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● PROJECTS ● THEORY ●
● NEWS ● COMMENT ●
● POPULAR FEATURES ●
VOL. 41. No 9 September 2012

EPE EVERYDAY PRACTICAL ELECTRONICS

INCORPORATING ELECTRONICS TODAY INTERNATIONAL

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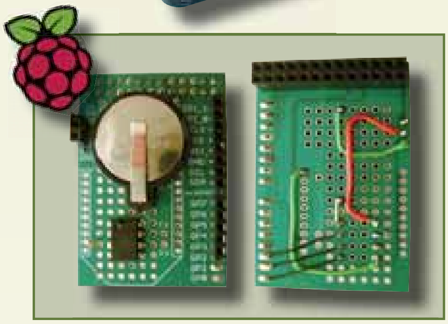


Our October 2012 issue will be published on Thursday 6 September 2012, see page 80 for details.

Projects and Circuits

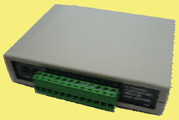
Series and Features

Regulars and Services

Hot New Products!

Here are a few of the most recent products added to our range. See website or join our email Newsletter for all the latest news.

4-Channel Serial Port Temperature Monitor & Controller Relay Board

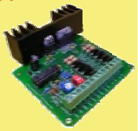


4 channel computer serial port temperature monitor and relay controller with four inputs for Dallas DS18S20 or DS18B20 digital thermometer sensors (£3.95 each). Four 5A rated relay channels provide output control. Relays are independent of sensor channels, allowing flexibility to setup the linkage in any way you choose. Commands for reading temperature and relay control sent via the RS232 interface using simple text strings. Control using a simple terminal / comms program (Windows HyperTerminal) or our free Windows application software.
Kit Order Code: 3190KT - **£84.95**
Assembled Order Code: AS3190 - **£99.95**

40 Second Message Recorder

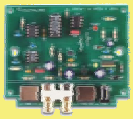
Feature packed non-volatile 40 second multi-message sound recorder module using a high quality Winbond sound recorder IC. Stand-alone operation using just six onboard buttons or use onboard SPI interface. Record using built-in microphone or external line in. 8-24 Vdc operation. Just change one resistor for different recording duration/sound quality. sampling frequency 4-12 kHz.
Kit Order Code: 3188KT - **£29.95**
Assembled Order Code: AS3188 - **£37.95**
120 second version also available

Bipolar Stepper Motor Chopper Driver



Get better performance from your stepper motors with this dual full bridge motor driver based on SGS Thompson chips L297 & L298. Motor current for each phase set using on-board potentiometer. Rated to handle motor winding currents up to 2 Amps per phase. Operates on 9-36Vdc supply voltage. Provides all basic motor controls including full or half stepping of bipolar steppers and direction control. Allows multiple driver synchronisation. Perfect for desktop CNC applications.
Kit Order Code: 3187KT - **£39.95**
Assembled Order Code: AS3187 - **£49.95**

Video Signal Cleaner



Digitally cleans the video signal and removes unwanted distortion in video signal. In addition it stabilises picture quality and luminance fluctuations. You will also benefit from improved picture quality on LCD monitors or projectors.
Kit Order Code: K8036KT - **£29.95**
Assembled Order Code: VM106 - **£44.95**

Most items are available in kit form (KT suffix) or assembled and ready for use (AS prefix).

Motor Speed Controllers

Here are just a few of our controller and driver modules for AC, DC, Unipolar/Bipolar stepper motors and servo motors. See website for full details.

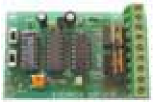
DC Motor Speed Controller (100V/7.5A)

Control the speed of almost any common DC motor rated up to 100V/7.5A. Pulse width modulation output for maximum motor torque at all speeds. Supply: 5-15Vdc. Box supplied. Dimensions (mm): 60Wx100Lx60H.
Kit Order Code: 3067KT - **£19.95**
Assembled Order Code: AS3067 - **£27.95**

Bidirectional DC Motor Speed Controller

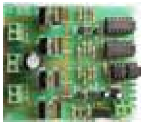
Control the speed of most common DC motors (rated up to 32Vdc/10A) in both the forward and reverse direction. The range of control is from fully OFF to fully ON in both directions. The direction and speed are controlled using a single potentiometer. Screw terminal block for connections.
Kit Order Code: 3166v2KT - **£23.95**
Assembled Order Code: AS3166v2 - **£33.95**

Computer Controlled / Standalone Unipolar Stepper Motor Driver



Drives any 5-35Vdc 5, 6 or 8-lead unipolar stepper motor rated up to 6 Amps. Provides speed and direction control. Operates in stand-alone or PC-controlled mode for CNC use. Connect up to six 3179 driver boards to a single parallel port. Board supply: 9Vdc. PCB: 80x50mm.
Kit Order Code: 3179KT - **£17.95**
Assembled Order Code: AS3179 - **£24.95**

Computer Controlled Bi-Polar Stepper Motor Driver



Drive any 5-50Vdc, 5 Amp bi-polar stepper motor using externally supplied 5V levels for STEP and DIRECTION control. Opto-isolated inputs make it ideal for CNC applications using a PC running suitable software. Board supply: 8-30Vdc. PCB: 75x85mm.
Kit Order Code: 3158KT - **£24.95**
Assembled Order Code: AS3158 - **£34.95**

AC Motor Speed Controller (600W)

Reliable and simple to install project that allows you to adjust the speed of an electric drill or 230V AC single phase induction motor rated up to 600 Watts. Simply turn the potentiometer to adjust the motors RPM. PCB: 48x65mm. Not suitable for use with brushless AC motors.
Kit Order Code: 1074KT - **£15.95**
Assembled Order Code: AS1074 - **£23.95**

See www.quasarelectronics.com for lots more DC, AC and Stepper motor drivers

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Order Code EPL500 - **£179.95**
Also available: 30-in-1 **£17.95**, 50-in-1 **£29.95**, 75-in-1 **£39.95** £130-in-1 **£49.95** & 300-in-1 **£79.95** (see website for details)

Tools & Test Equipment

We stock an extensive range of soldering tools, test equipment, power supplies, inverters & much more - please visit website to see our full range of products.

Advanced Personal Scope 2 x 240MS/s

Features 2 input channels - high contrast LCD with white backlight - full auto set-up for volt/div and time/div - recorder roll mode, up to 170h per screen - trigger mode: run - normal - once - roll ... - adjustable trigger level and slope and much more.
Order Code: APS230 - ~~£499.95~~ **£394.95**

Personal Scope 10MS/s

The Personal Scope is not a graphical multimeter but a complete portable oscilloscope at the size and the cost of a good multimeter. Its high sensitivity - down to 0.1mV/div - and extended scope functions make this unit ideal for hobby, service, automotive and development purposes. Because of its exceptional value for money, the Personal Scope is well suited for educational use.
Order Code: HPS10 - ~~£189.95~~ **£139.95**

See website for more super deals!

No.1 for KITS

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AUDIO Kits for Electronic Enthusiasts

High Performance 12V Stereo Amplifier Kit
Cat. KC-5495

An ideal project for anyone wanting a compact and portable stereo amp where 12V power is available. No mains voltages, so it's safe as a school project or as a beginner's first amp. Performance is an excellent with 20WRMS per channel at 14.4V into 4 ohms with THD of less than 0.03%. Shortform kit only.

BEST SELLER!

£16.50*

- 12VDC
- Recommended heatsink **(use HH-8570 £2.25)**
- PCB: 95 x 78mm

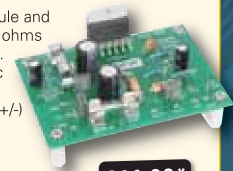
"Pre-Champ" Versatile Preamplifier
Cat. KC-5166

This tiny preamp was specifically designed to be used with the 'Champ' amplifier KC-5152 below. Unless you have a signal of sufficient amplitude the 'Champ' will not produce its maximum power output. The 'Pre-Champ' is the answer with a gain in excess of 40dB, which is more than enough for most applications. You can vary the gain by changing a resistor and there is even provision on the PCB for an electret microphone. Use **AM-4010 £0.81**.

- Power requirement: 6-12VDC.
- Kit includes PCB and electronic components
- Can be battery powered
- PCB: 46 x 36 mm

£3.50*

50 Watt Amplifier Module
Cat. KC-5150



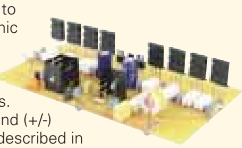
Uses a single chip module and provides 50WRMS @ 8 ohms with very low distortion. PC Board and electronic components supplied. Requires heatsink and (+/-) 35V power supply. See website for full specs.

- PCB: 84 x 58 mm
- Heatsink to suit **HH-8590 £5.25**

£11.00*

Studio 350 - High Power Amplifier
Cat. KC-5372

Delivers a whopping 350WRMS into 4 ohms or 200WRMS into 8 ohms. It offers real grunt using a high power MJ21193/4 transistor and is super quiet with a very low signal to noise ratio and harmonic distortion. This kit is supplied in short form with PCB and electronic components. Kit requires heatsink and (+/-) 70V power supply as described in instructions. See website for more specifications.



£63.50*

"The Champ" Audio Amplifier
Cat. KC-5152

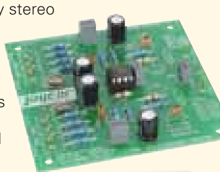
This tiny module uses the LM386 audio IC, and will deliver 0.5W into 8 ohms from a 9V supply making it ideal for all those basic audio projects. It features variable gain, will happily run from 4-12VDC and is smaller than a 9V battery, allowing it to fit into the tightest of spaces.

£3.00*

- PCB and electronic components included
- PCB: 46 x 26 mm

Universal Stereo Preamplifier
Cat. KC-5159

Based around the low noise LM833 dual op-amp IC, this preamp is designed for use with a magnetic cartridge, cassette deck or dynamic microphone. The performance of this design is far better than most preamps in many stereo amplifiers, making it a worthy replacement if your current preamp falls short of expectation. It features RIAA/IEC equalisation, and is supplied with all components to build either the phono, tape or microphone version.



£6.25*

- +/- 15VDC
- If power is not available in your equipment use **MM-2007 £3.50**.
- PCB: 80 x 78 mm

Crazy Cricket & Freaky Frog Kit
Cat. KC-5510

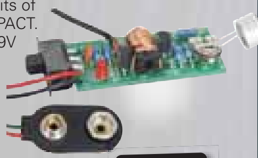
A fun first project for a budding electronics enthusiast. Designed to imitate the chirping noise of a cricket or gentle croaking of a frog (alternates at power up), while keeping its location secret to annoy other family members. It activates in darkness and stops when disturbed by light. Kit supplied with PCB, pre-programmed micro battery and electronic components.

- PCB: 30 x 65mm

£7.25*

Miniature FM Transmitter
Cat. KE-4711

This unit is a two transistor two stage transmitter that has the benefits of being VERY COMPACT. Kit contains PCB, 9V battery and components, and makes an ideal, inexpensive beginners kit.



- 9VDC
- PCB: 45 x 23 mm

£5.00*

The 'Flexitimer'
Cat. KA-1732

Now in it's 3rd revision by Jaycar, the flexitimer remains one of our most versatile short form projects. The flexitimer runs on 12-15V DC and switches the on-board relay once or repeatedly when the switching time is reached. Switching time can be set between 7 seconds and 2 hours in fixed steps.

- PCB size: 74 x 47mm

£7.25*

Low Cost Programmable Interval Timer
Cat. KC-5464

Here's a updated version of the very popular low cost 12VDC electronic timer. It is link programmed for either a single ON, or continuous ON/OFF cycling for up to 48 on/off time periods. Selectable periods are from 1 to 80 seconds, minutes, or hours and it can be restarted at any time. Kit includes PCB, program micro and electronic components.

- PCB: 102 x 42mm

£12.75*

Jacob's Ladder High Voltage Display Kit MK2
Cat. KC-5445

With this kit and the purchase of a 12V ignition coil (available from auto stores and parts recyclers), create an awesome rising ladder of noisy sparks that emits the distinct smell of ozone. This improved circuit is suited to modern high power ignition coils and will deliver a spectacular visual display. Kit includes PCB, pre-cut wire/ladder and electronic components.

£15.75*

- 12V car battery, 7Ah SLA or > 5A DC power supply required
- PCB: 170 x 76mm

THOUSANDS SOLD!

Theremin Synthesiser Kit MkII
Cat. KC-5475

£27.25*

The ever-popular Theremin is better than ever. It's easier to set up with extra test points for volume adjustment and power supply measurement and it now runs on AC to avoid the interference switchmode plugpacks can cause. It's also easier to build with PCB-mounted switches and pots to reduce wiring to just the hand plate, speaker and antenna and has the addition of a skew control to vary the audio tone from distorted to clean.

- Complete kit contains PCB with overlay, pre-machined case and specified components
- PCB: 85 x 145 mm

DHL

5-10 working day delivery

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Order online: www.jaycar.co.uk

Jaycar Electronics

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See notes on **Readers' Technical Enquiries** below – we regret technical enquiries cannot be answered over the telephone.

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Sourcing parts for projects

Following on from last month's popular and ingenious *Ultrasonic Cleaner* project, this month, we have another use for high-powered ultrasonic transducers in the shape of a boat anti-fouling project – instead of labour-intensive, dirty and expensive scraping and the application of unpleasant toxic paint, you now have the option of a clean, inexpensive and simple-to-install electronic circuit that will keep the barnacles at bay. It's not just for 'sea dogs', this project will work equally well for inland waterway craft.

Going through the component list of these projects, I did check to make sure the rather specialised piezoelectric transducers needed are readily available here in the UK – the project originates from our partners *Silicon Chip* magazine 'down under'. At first, I was rather discouraged; the usual suspects of RS, Farnell or Maplin seemed to stock nothing like it. Next, I tried the planet's flea market – eBay, and, of course, they are available there, but you have to order them from China. I've never ordered one-offs like this from China, and although I have no reason to doubt the honesty or reliability of Chinese suppliers on eBay, they wouldn't normally be my first port of call.

The answer, as always with *Silicon Chip* projects, is to go to their recommended suppliers in Australia. I know some readers are a little apprehensive about ordering from what must be the most distant suppliers to the UK, but please do consider these three points: 1) Jaycar and Altronics have been successful and reliable partners with *Silicon Chip* for several years; 2) you are ordering from an English-language website with email and, if necessary, phone contacts, 3) despite the heat, unusual animals and uncanny ability to beat us at cricket (well, usually), Australia is, in many ways, one of the easiest foreign countries to do business with – they have a similar legal system, the same language and strong cultural links to us.

Yes, it takes a little longer for components to arrive, but we are talking an extra week – *not* weeks. *EPE* has no financial interest or relationship with these suppliers, but we do have a strong interest in our readers being able to source the parts needed for the projects we publish. Please do not let the geography put you off ordering parts or whole kits from these reliable suppliers.

NEWS

A roundup of the latest Everyday News from the world of electronics

Lord Sugar sweetens TV access by Barry Fox

After more than a year of delays, which were turning the name YouView into an industry joke, the long awaited hybrid Freeview/Internet set-top box is now ready for launch. First impressions, from live demos given in London recently, suggest the wait has been well worthwhile.

YouView chairman, Lord Sugar (Alan Sugar, founder of Amstrad) and CEO Richard Halton, confirmed that the technical specification has now been locked down, 2500 home trialists have enthused; eg, on Twitter and twin-tuner PVR boxes are already in production by Humax. The first batches were due in shops at the end of July for £299.

'It is a great moment in British television' said Lord Sugar. 'This is British technology. It was invented and designed here in the UK, not California. YouView is not Internet on TV, it's a whole new way of experiencing TV.'

YouView chairman Lord Sugar (right) and CEO Halton at the launch of their new set-top 'box'

The core aim of YouView is to provide an EPG (electronic program guide) which seamlessly combines live off-air Freeview DTTV (digital terrestrial television) with live IPTV (internet protocol television). The EPG looks forward though 100 Freeview channels of free-to-air digital TV and radio programming for the next seven days, and backwards over the last seven days (or more, eg, for archived series) through online catch up TV services such BBC iPlayer.

'YouView seamlessly combines the worlds of catch-up and live TV, on the living room TV' says Halton. 'There will 15,000 programmes on back offer at any time, with 3000 new per week'.

A search option finds on-demand content by programme or even an actor's name.

YouView is backed by the BBC, ITV, Channel 4 and Channel 5, transmitter network operator Arqiva, and telecoms providers BT and TalkTalk. Together, the seven partners have spent £70m.

BT and TalkTalk will offer additional content and services to customers. But a YouView box can be used with any ISP's broadband connection.

YouView will control the EPG and let any reputable content provider appear on it – for a fee set by an as-yet unpublished menu of prices. Over 300 content partners have already expressed interest, says Halton. Sky's Now TV and Scottish commercial STV will be first to go live.

'I'd not be surprised to see a £99 'Zapperbox', without a PVR (personal video recorder) function and with just a single tuner, in a couple of years' says Lord Sugar. 'There is no reason why other manufacturers can't become licensees. It is not a closed shop.

'It's normal to start with a top-end model. But I see this as a template, or carcass, of what's to come. But it will take a little time. For instance, the PVR disc is not just for recording, it is also used for buffering.

'There is no reason why the Zapperbox circuit board should not be built into an IDTV (integrated digital television) instead of a Freeview tuner.

'Anyone who wants to be a broadcaster can be – by offering an Internet TV channel and paying say £50,000 to be on the YouView EPG. It's an open but regulated platform with PIN-protected parental controls.'

Commercial channels will be ad-funded, with catch-up programmes not necessarily streaming the same adverts that went out with the live broadcast. 'YouView will not be selling anything' say Halton and Sugar.

Viewers will only know they are watching by broadband instead of off-air by the progress bar at the bottom of the catch-up TV screen. 'Our marketing will warn about data costs and data caps' assures Halton.

'I have spent my time in this industry making complicated technology easy to use. There will be no thick manual, just instructions on how to plug into three things – the aerial, broadband and TV. Anyone who can't understand that probably shouldn't be watching TV'.

National Radio Centre opens at Bletchley Park

The The Radio Society of Great Britain's National Radio Centre (NRC) has formally opened at Bletchley Park.

The Centre is a world-class showcase for radio communications technology, which provides the opportunity to get 'up close and personal' with the history and technology of radio communications.

From the first inventors in the late 19th century through Marconi to future radio developments, visitors will find films, interactive displays, hands on experiments and even the opportunity to 'go on the air' using a state-of-the-art shortwave radio station.

A part of the Bletchley Park Heritage site, the NRC, with its focus on radio communications today, fits in well with other parts of the Bletchley Park museum, which show how radio communications have played a pivotal part in the history of code-breaking, counter intelligence and national defence.

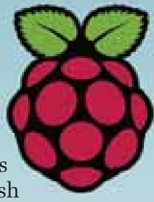
The NRC features a small cinema and extensive descriptions of the history of radio communications, interspersed with examples of radio equipment across the 20th century. A wall-long display with video commentary, shows how the electromagnetic spectrum from DC to light is used today.

Interactive demonstrations of radio technology illustrate the basic ideas inside every radio.

Commenting on the Centre, the President of the Radio Society of Great Britain, David Wilson, said 'We are proud to bring this outstanding exhibition and learning facility into operation. It is probably the leading exhibition of radio communications technology in the UK, brought to life with vivid realism and providing the opportunity for visitors to learn about this major economic force in the world today.

For further details about the NRC, see: **www.bletchleypark.org.uk**

Raspberry Pi Zone



Need an extra helping of Raspberry Pi? There's a new section on *EPE's Chat Zone* dedicated to this exciting, low-cost British single-board computer. For more details, see: **www.chatzones.co.uk**

UK Broadband survey

Thinkbroadband.com, a broadband news and information site, is calling for UK broadband users and non-users to participate in a new nationwide 'Big Broadband' survey, see: www.broadbandsurvey.org.uk

The survey will give participants the chance to air their views and gripes on broadband, and will reveal how much the UK spends on broadband, why they switch between providers, how quickly faults are remedied, and how often they exceed their data quota. It will also show which UK regions suffer the most from poor broadband service and how reliant we are on the 'net'.

Matrix modules for data-logging and control system development

Matrix has announced the launch of nine new expansion modules for its popular MIAC controller.

The MIAC E-system design suite consists of a rugged MIAC controller, nine expansion modules and the Flowcode graphical programming software, which allows engineers to quickly develop industrial control and data-logging systems. The MIAC e-system design suite provides a set of parts that can create a range of electrical systems in a short time.

The MIAC and the expansion modules connect together using the CAN bus. The Flowcode graphical programming software takes care of all CAN bus communications between the modules, so no knowledge of CAN is needed. Integration with other electronic systems is a key objective and the designers have made it easy to link the modules to the Internet using TCP/IP, to mobile devices using Bluetooth or Wi-Fi, to Zigbee-enabled systems, RS485 and RS232 systems, and to PCs using USB. The system is also compatible with low voltage protocols such as TTL, I2C and SPI, which is designed to make the modules useful for general lab test and measurement purposes.

Flowcode V5 for ARM and AVR/Arduino

Matrix has also brought out new versions of its electronic system design software: Flowcode version 5 for ARM microcontrollers and Flowcode version 5 for AVR microcontrollers. (These follow the launch of Flowcode 5 for PIC microcontrollers.)

New expansion modules from Matrix

The new Flowcode is designed to speed up the process of learning how to develop electronic systems, and also offers practising engineers a range of new features that make designing microcontroller-based circuits easier and quicker.

New functional features include automatic documentation, support for a wider range of variable types, C code management and customisation, and new components.

Flowcode V5 for AVR will also now natively support Arduino devices and the XMEGA range of AVR devices. It is available as a download via the Matrix website and its list of distributors worldwide.

Further details are available at: **www.matrixmultimedia.com**

Code breakers mobile challenge!

It's the stuff of GCHQ and MI5 storylines. The Enigma E2 mobile phone claims to have an 'unbreakable encryption that will challenge the world's best code breakers'. Preventing anyone from listening in, 'Crypto' calls on the Enigma E2 are '100% secure', using unbreakable and unique codes via a unique second SIM card.

Especially important for those wanting to protect against business espionage, terrorism or need to keep their lives private. It takes seven seconds or less to set up a highly encrypted call by simply pressing the 'crypto' button to call another Enigma phone. The phones use secure keys, 1024-bit RSA asymmetric encryption and 256-bit AES symmetric encryption to authenticate each other.

The Enigma E2 can also be used to make unencrypted calls to ordinary mobile phones. It has GPRS internet access and Bluetooth hands-free, but both of these are kept separate from the 'crypto' side of the phone. Software upgrades are also available to offer encrypted text and picture messaging.

Would be James Bonds would do well to remember its World War Two namesake, and that given enough effort, almost any code can be broken!

The Enigma E2 costs £1320 from **www.tripleton.com**

Designing and Installing a HEARING LOOP For the deaf

Part 1: By JOHN CLARKE

Many people have hearing impairment. Whether they are watching TV, listening to radio or music, attending a concert, meeting or religious service, they have difficulty hearing, or understanding what is going on – and that may be in spite of using a hearing aid. Hearing loops, which inductively couple an audio signal to a hearing aid, are an increasingly common method of helping ease this difficulty.

JUST because you have a hearing aid does not mean that your hearing problems are solved. When you have normal hearing, your ears are very good at discriminating between noise and the sounds you want to hear. Not so with a hearing aid, particularly if you are wearing only one.

The hearing aid is basically a microphone, amplifier and earpiece. Unfortunately, the microphone picks up all sounds and noise, and then amplifies all signals by the same amount. The wearer often has great difficulty discerning what is going on.

In many situations, this problem can be largely overcome by a hearing loop, fed by an audio amplifier. The loop is placed around the room or hall and the radiated signal is then picked up by a hearing aid fitted with a T-coil (or Telecoil; see the panel, 'The origin of the Telecoil').

Alternatively, the signal can be picked up via a cochlea implant or even a loop receiver, as described elsewhere in this issue, driving conventional headphones/earbuds.

Hearing loss increases with age, so it is common for hearing loops to be used, for example, in halls and places of worship which older people frequent. In fact, many modern buildings are so equipped these days.

In the home

In the home, of course, the problem can be just as difficult, especially when shared with those without hearing impairment. But it is unusual for hearing loops to be installed in the home.

Until now, that is: in this article we describe how to set up a basic hearing loop for the home or for small to quite large meeting rooms, to IEC (International Electrotechnical Commission) standards – and how to drive it.

This could be done using a commercially made amplifier specifically intended for hearing loop applications, but equally it could be a standard commercial amplifier or even one of the amplifier designs published in previous issues.

Professional hearing loop installations can cost many thousands of pounds, especially when retro-fitted (most new public buildings these days have them installed during construction in appropriate areas as a matter of course).

However, a do-it-yourself installation along the lines set out in this article can provide excellent results, and save a heap of money. It is relatively easy to fit and can be made small or quite large, depending on the area needed to be covered.

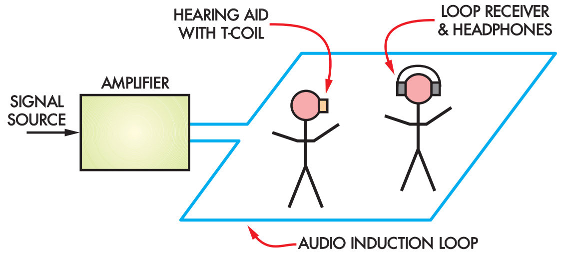


Fig.1: the basic arrangement for a hearing loop. Signal from the room PA is amplified and coupled into the loop. The resulting magnetic field is detected by suitably equipped hearing aids or receivers.

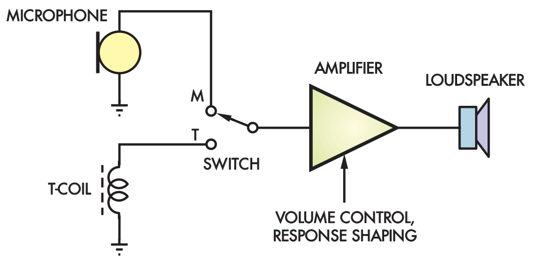


Fig.2: a hearing aid equipped with both T-coil and microphone to cover both signal sources. Many hearing aids will have a switch to select both. Obviously, the loudspeaker is tiny enough to fit in the ear.

What's a hearing loop?

In its simplest form, a hearing loop system comprises a signal source, an amplifier and a large loop of wire around a room or hall. Since this loop forms a coil with an AC current flowing through it, it radiates an electro-magnetic field which varies in sympathy with the signal source.

This radiated signal can be detected by a hearing aid equipped with a T-coil or a loop receiver (with headphones) designed for the purpose. Fig.1 shows the arrangement, and we will explain just how this works shortly.

If you want to set up a hearing loop in your home, you should be able to get satisfactory results without any special equipment. For larger setups in halls, the magnetic field produced by the signal in the loop needs to be set to the required level, so that all hearing aids with T-coils will operate correctly.

In a later article in this series, we will show how to build and calibrate a signal level meter to measure signal levels from the installed loop.

Our hearing loop is suitable for use in a home, office, hall, church or similar building. We include design graphs and tables to make it easy to select the wire size and its length, along with the amplifier power requirements for a particular installation.

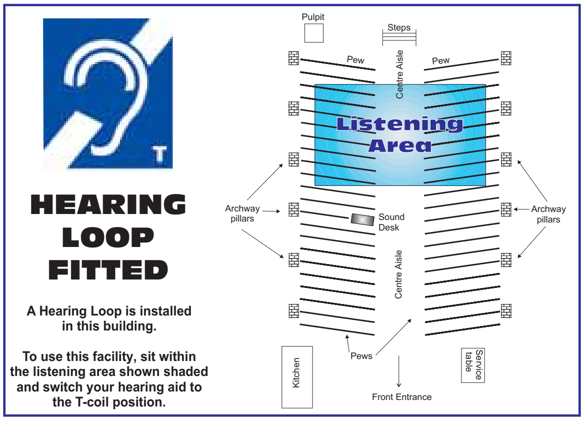
For large loops, say in a community hall or church, you will need a signal pre-conditioner. In a later issue we will present a suitable design to allow a standard amplifier to be employed. The pre-conditioner provides stereo signal mixing, audio compression, treble boost to provide compensation for loop inductance and treble rolloff above 5kHz.

Other articles will provide circuit and construction details for an induction loop receiver (see p.22 of this issue) and a microphone loop driver.

That's all to come later; first, let's describe the basics of a hearing aid.

How does a hearing aid work?

In its simplest form, a hearing aid comprises a microphone, an amplifier and a miniature loudspeaker. In normal use, the sound picked up by the microphone is amplified and



Where a hearing loop is fitted, it doesn't usually cover the entire area. Hence a 'map' is needed, such as this one in a church, to show people with hearing aids where to sit.

The hearing loop (white figure-8) is laid out here for testing before permanent installation under the floor.

A commercial hearing loop amplifier, in this case the model 1077 from Auditec. It's a current amplifier, which has some advantages in hearing loop use, but conventional voltage amplifiers are certainly usable as well

processed, depending on the complexity of the hearing aid. The amplified signal is then reproduced via the loudspeaker, which is closely coupled to the wearer's eardrum at a level which compensates for the loss of hearing. Fig.2 shows the general aid internal arrangement.

Better, modern hearing aids also include signal processing to try to present the clearest audio to the wearer. And the best also include a Telecoil (or T-coil), which comprises a coil of wire on a ferrite core, and a switch on the hearing aid which selects the T-coil or microphone as the input source.

Originally used to couple the electromagnetic energy from a specially equipped telephone into the hearing aid (hence the name), their use has now expanded to be able to detect an electromagnetic signal from a hearing loop, where fitted. Not all hearing aids have a T-coil and obviously, without one, there is absolutely no advantage from either special telephones or hearing loops.

Fig.3 shows the magnetic field produced by the hearing loop (sometimes referred to as an audio induction loop) and how this couples into the T-coil. Normally the induction loop is horizontal and the T-coil is vertical (for a person who is sitting or standing). Any variation of the T-coil from its vertical position will reduce the received signal.

There is nothing to stop the orientation of the hearing loop being vertical, allowing hearing aid wearers to use the loop when lying along the horizontal.

One disadvantage of the T-coil inductor is that it produces a signal which rises in level with increasing frequency. This is because the induced voltage is proportional to the rate of change of the magnetic field and so higher frequencies will give a higher voltage. This rising response is normally compensated for within the hearing aid to produce a flatter frequency response.

Here's a commercial hearing loop receiver which drives standard headphones. Or you can build your own: see the article on page 22!

Why T-coil

So why would a person with a hearing aid prefer to listen via the T-coil instead of listening directly to the sound from a public address or similar sound system? After all, a hearing aid is designed to pick up sound, amplify it and tailor the frequency response to suit the individual user.

As already noted, people with normal hearing have little trouble discriminating between unwanted noise and the sounds they want to hear. By contrast, the wearer of the hearing aid finds that in a room full of people or in a noisy environment, all they hear is a whole lot of noise and it prevents them from following any one sound or conversation. To that you can add natural reverberation in a large room, the noise of people moving about and maybe background music.

The room, especially if it's reasonably sized, may well have some form of public address system fitted. That's fine for those with normal hearing but, ironically, a PA can introduce more reverberation, cause hearing aid overload (distortion) and can raise bass levels to further muddy the sound clarity.

The solution is to channel the signal directly from the public address system into an audio induction loop to be picked up by the hearing aid T-coil. The resulting sound is clearer because it only contains that broadcast by the sound system and hence extraneous sounds from other people and reverberation are absent.

Not perfect

As good as it is, listening via a T-coil is not perfect: the hearing aid user can feel isolated from the rest of the group of people in the building because they do not hear the ambient sounds of the people around them.

To overcome this, some hearing aids include switching to select three options: T-coil, T-coil plus microphone and microphone only. The T-coil plus microphone setting mixes the signals to allow ambient sounds and the broadcast (PA) signal to be heard, but even this can be a compromise.

Of course, there is no perfect electronic cure for hearing loss, so always protect your hearing while you have it. It is forecast that in the next 10 to 20 years we'll see an explosion in the number of younger people with irreversible hearing damage, caused (in particular) by years of exposure to loud rock music (why do bands have to play so loud?) and more importantly, the massive use of ear-buds at excessive volume from cassette players, then CD players and most recently MP3/MP4 players and mobile phones.

Designing a hearing loop system

Before embarking on designing and installing a hearing loop, you need to decide whether the building is suitable for installing a loop. For many buildings, the loop can be installed beneath the floor, especially if it is timber construction and there is access to the underside of the flooring. Where there is a concrete floor, the loop could be placed around the floor under carpet or behind skirting boards. Alternatively, the loop could be placed in the ceiling, provided it is not too high above normal listening level.

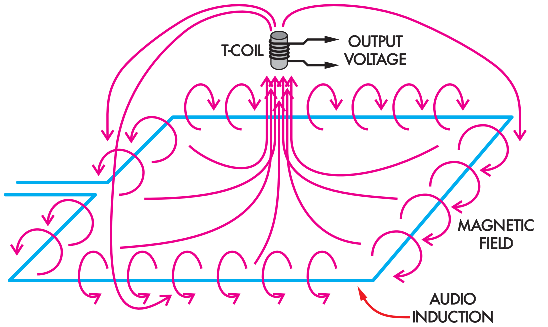


Fig.3: Current flowing in the hearing loop produces a magnetic field that couples into the T-coil. Voltage is produced across the T-coil terminals.

Installing a hearing loop in buildings made with steel frames or reinforced concrete is more difficult, because the steel tends to reduce the magnetic field strength. The solution may be to provide more current drive in the loop with a larger amplifier and/or by using more complex loop designs.

For most installations, a single loop is all that is needed. Loop performance can be checked before it is permanently installed by simply running the loop wire temporarily around the area (eg, on the floor) where required.

An important factor to consider when deciding on the positioning of a loop is interference from the mains power lines. In particular, phase-controlled light dimmers for stage and auditorium lighting often cause a buzzing sound, predominantly at 100Hz. The interference will be highest when the lamps are dimmed.

Fluorescent lamps can cause interference when they are switching on, but do not usually cause problems once lit. Another source of interference is close proximity to computers and monitors; in fact, anything with a 'switch-mode' power supply.

We'll be describing a *Hearing Loop Level Meter* in a future article, which can be used to check the background interference levels down to 21dB below a 100mA/m reference.

What level?

According to the Australian standards (AS60118.4-2007), environmental audio frequency background field levels should be below –20dB 'A-weighted', with respect to a 100mA/m reference field (or –40dB below 1A/m) using a slow (S) time weighting of 1s.

We have reservations about whether this level is sufficiently low for satisfactory hearing loop performance. The *Hearing Loop Level Meter* will also measure noise using a wider frequency response than the A-weighting provides. This can give a more realistic indication of whether noise will be intrusive.

Another consideration is whether the loop wire will be running close and parallel to signal wires in a PA system, such as for microphones. This has the potential to cause instability in the sound system, although it is usually no more severe than feedback caused by loudspeaker wiring running close to the microphone cables.

Further problems may occur with dynamic, electret and UHF radio microphones, and guitars with magnetic pickups.

The origin of the Telecoil

Hearing aids installed with a Telecoil or T-coil began as a solution to a problem that occurs when using a hearing aid with a telephone. The name Telecoil originates from the words telephone and coil.

To understand the problem you need to be aware that there is coupling between the telephone mouthpiece and the telephone earpiece, so as you speak some of the sound is heard through the earpiece. The coupling is called 'side-tone', and is deliberately introduced to prevent the telephone sounding dead when speaking.

This can cause a problem when using a hearing aid. When it is brought close to the earpiece of a telephone, the hearing aid often produces a loud-pitched squeal, or feedback. This is caused by the microphone on the hearing aid picking up sound that is amplified and reproduced by the hearing aid loudspeaker, which is then received by the telephone handpiece and then further re-amplified by the hearing aid and so on.

To allow a hearing aid wearer to use a telephone, without this problem occuring, the telephone is modified to include a wire loop that is driven by the same signal as the telephone loudspeaker. The loop produces a small magnetic field that varies in sympathy with the signal.

To utilise this feature, the hearing aid needs to include a Telecoil (T-coil) that detects the signal from the phone's magnetic field. When required to be used in this way, the hearing aid is switched to the 'T-coil' position, disabling the hearing aid microphone and thus avoiding the audio feedback.

Some telephones include a Telecoil already installed within the handpiece; some may need one fitted as an accessory.

Some hearing aids are designed to automatically switch over to the T-coil position in the presence of a strong DC magnetic field. The magnet in the telephone earpiece provides this field.

Due to the success of the T-coil in hearing aids with telephones, its application has broadened to where hearing loops are now commonly used wherever sound needs to be available for the hearing impaired.

A 'behind the ear' hearing aid. The tube at the top feeds into the ear canal, fed by the miniature loudspeaker at the top of the unit. Controls on the back of the unit include a volume control, power switch and the all-important T-coil/microphone switch.

It is wise to test for these problems with a temporary loop installation. Problems will be evident if the sound seems distorted or has a 'metallic' quality. An oscilloscope can also be used to monitor the sound system signal for instability.

Note that an audio induction loop setup will not cause direct acoustic feedback – the squeal associated with audio coupling of microphones and guitars to loudspeakers.

Spill

Generally, the area where a hearing aid will receive the signal is within the loop itself. Outside the loop, the signal level drops off. Fig.4 shows the measured field strength of a 10m × 10m square loop at a height of 1m above the loop. The signal is reasonably constant (to within 3dB) within the loop area, but drops off just outside the loop. Any signal outside the loop is called the 'spill'.

Spill means that the signal is not secure and might be intercepted from outside the building, simply by using a T-coil-equipped hearing aid. If security is important, that is a consideration. Spill also means that if more than one loop is installed in a building, then measures are required to prevent interference between them.

More than one loop will be required where a very large area needs to be covered. If each loop broadcasts the same signal, then using out-of-phase adjacent loops can minimise signal loss at the loop junction.

Where the signal in each loop is different (eg, in a multi-cinema theatre) the loop design must prevent any signal spill into adjacent loops. Special loop designs enable spill to be minimised. For more information on spill control, see Ampetronic's website: www.ampetronic.com

Coverage area

In many cases, it is only necessary to provide loop coverage for part of a room or hall, rather than attempt to provide for the full area. For example, where a hall has seating for say 500

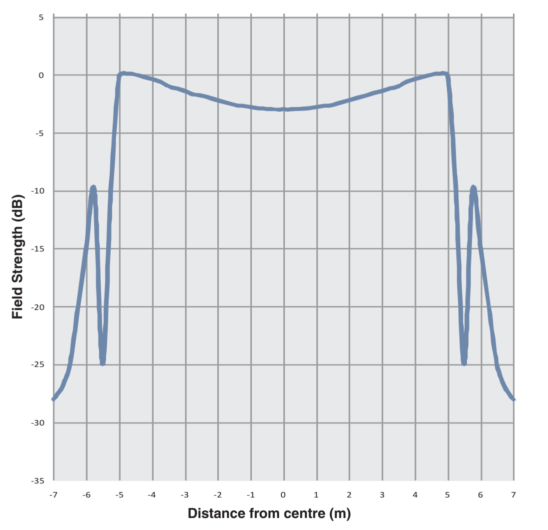


Fig.4: field strength over loop area for a 10m square loop at a height of 1m above loop.

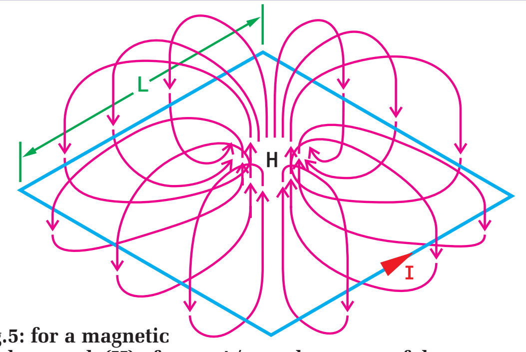


Fig.5: for a magnetic field strength (H) of 100mA/m at the centre of the square loop, the current required through the loop of side length *L* is *I*=*L*/9*n* amps, where *n* is the number of turns.

people, you may only need to provide hearing loop coverage for 50 seats or perhaps even less.

This would mean that a map would be required to show potential users the designated listening area and/or any booking system would need to provide priority for hearing impaired listeners within that area. A smaller loop also means that a lower-powered amplifier can be used.

Amplifiers for hearing loops

An audio amplifier is required to 'drive' the loop, and designers have three choices: using a commercial hearing loop amplifier; using a standard commercially made amplifier; or you build your own.

Most commercial amplifiers specifically made for hearing loop use are 'current' amplifiers, whereas 'ordinary' amplifiers, including ones you would build yourself, are 'voltage' amplifiers.

Current amplifiers have the advantage that the loop current does not vary with frequency, which would normally occur due to the inductance of the loop. However, standard voltage amplifiers can be used, although it is true that they provide reduced current to the loop as the frequency rises. This is easily fixed, in most cases, with some judicious treble boost.

And with our signal pre-conditioner for power amplifiers, to be described in a future issue, using a voltage amplifier becomes very practical.

Minimum load for a voltage amplifier

One requirement when using a voltage amplifier is that the loop must be designed to suit its minimum load, typically 4Ω. Hence, the design is based on the size of the loop and wire gauge required to provide a 4Ω DC resistance.

Once you have decided on the hearing loop dimensions, you add up the length of wire sides (almost invariably the 'loops' are rectangular or square) required to make up the loop (don't forget the wire between the loop and the amplifier). Then the gauge of wire to provide a 4Ω load is selected from Table 1.

That's not the full story however, because the wire must be able to carry the current needed to produce the required magnetic field strength of 100mA/m (millamps/metre). This 100mA/m field strength is the standard long-term average signal level. With normal programme material, peak signals can be 12dB higher, or up to 400mA/m.

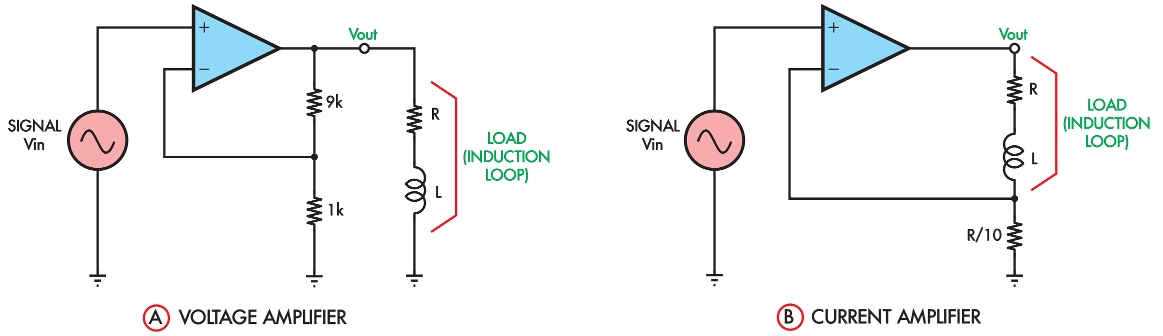


Fig.6 (left): a voltage amplifier driving a hearing aid loop load will produce less current in the loop with rising load impedance. Fig.7 (right): a current amplifier driving a hearing aid loop load will maintain current in the loop with rising loop impedance. More on this subject next month.

To allow for this, we have set a large factor of safety for the wire current rating by restricting average wire current to 5A/square mm when the wire could easily accept 8A to 10A continuously.

Calculation of the current requirements to produce the 100mA/m field strength (H) at the centre of a square loop and along the same plane as the loop uses the equation:

Current (A) = L(m)/9n

Where *L*(m) is the length of the side in metres, and *n* is the number of turns.

For the purposes of loop design, a rectangular loop can use the same equation, with *L* as the smaller of the rectangle sides.

As an example, when using the equation for a single-turn 9m square loop, a current of 1A is required to produce the 100mA/m field. For a 2-turn loop the current requirement to produce that same field is halved, to 0.5A.

How much amplifier power?

The amplifier power needed must allow for the signal to be +12dB over the base signal level, without overload (ie, clipping). So the required amplifier power requirement will be (current required for 400mA/m field strength) squared, multiplied by the 4Ω load.

As an example, if the current required is 1A, the power will only be 4W. If it is 4A, the power required will be 64W.

Listener's height

Another important factor to consider is that the maximum field strength lies in the same plane as the loop and will be lower at a distance above (or below) the plane of the loop. So, a design for monitoring signal in the same plane of the loop will not deliver that field strength at a higher level above the plane.

For most hearing loop installations, the loop is either placed just below the floor, at floor level or in the ceiling. Typically, this means that the listener's hearing aid is about 1.7m above or below the plane of the loop.

Fig.8 shows a graph of the extra current and power required for height offsets above or below the loop plane. To use the graph, divide the distance that the hearing aid will be above or below the loop plane by the shorter side length of the loop. If the loop has a 5m shorter side and the height

Table 1: Loop wire and current calculator

Wire size	Wire cross section area (mm^2)	Wire current capacity (based on $5A/mm^2$) (A)	Ohms per metre (Ω/m) (based on 0.017241Ω mm^2/m at 20°C)	Wire length required for 4Ω (For figure-8 wire use half this length)	Maximum square loop size (two turns)	Current for 100mA/m for max. loop size (A)	Current required for 1.7m above or below loop (A)
1 x 0.25mm	0.049	0.245	0.351	5.7m	0.7m square	0.078	-
1 x 0.315mm	0.07793	0.389	0.2212	18m	2.25m square	0.25	1.50
1 x 0.5mm	0.1963	0.982	0.0878	45m	5.63m square	0.63	1.01
14 x 0.14mm	0.21555	1.077	0.080	50m	6.25m square	0.70	1.05
14 x 0.18mm	0.3626	1.81	0.0484	84m	10.5m square	1.17	1.40
14 x 0.20mm	0.43982	2.20	0.039	104m	13m square	1.44	1.58
19 x 0.18mm	0.48349	2.42	0.03566	112m	14m square	1.56	1.64
20 x 0.18mm	0.50894	2.54	0.03388	118m	14.75m square	1.64	1.71
24 x 0.20mm	0.75398	3.77	0.02287	176m	22m square	2.44	2.45
41 x 0.20mm	1.28805	6.44	0.013387	298m	37.5m square	4.17	4.18

When you've decided on a loop dimension, use this to read off the nearest wire size and length required to make a 4Ω load.

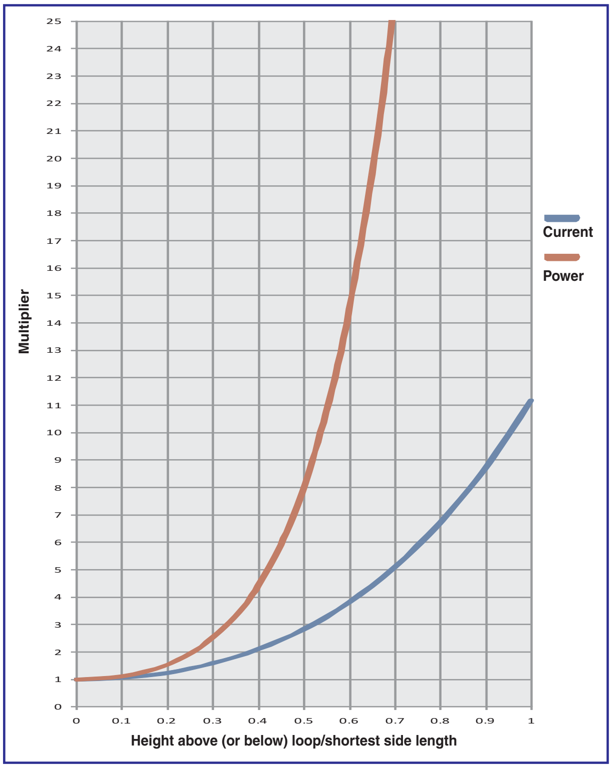


Fig.8: extra current and power are required for height offsets above or below the loop plane to maintain field strength.

is 2m above the loop, the division gives us 0.4. Comparing 0.4 on the graph gives us a multiplier of about 2.1 times more current that must be applied to the loop to maintain the field strength at 2m above (or below) the loop plane.

While the current needs to be 2.1 times greater, power requirements must be 4.4 times greater. This is where larger loops are better in this respect because the height above or below the loop plane is relatively small compared to the loop side dimension.

This fact is important to consider because users of the induction loop are seldom all the same height, nor do they always remain at the same height. They might stand some of the time and sit for other times, or they could be in a wheelchair. Ideally, the loop should be sized so that the field strength does not vary by more than 3dB between the lowest and highest listening heights.

The graph of Fig.8 can also be used to determine the variation in field strength with changes in listening height. That is because the current is directly proportional to field strength. If the listening height is changed so that more current is required in the loop to maintain field strength, then that means that the field strength will be lower at that height if the current is not increased to compensate.

Height comparison

Now, let's compare the variation in field strength between when a person is standing, and when seated. We choose 1.7m as the expected highest listening point above the loop plane, noting that hearing aids are at ear level rather than the height of the person. We choose 0.5m as the lowest expected listening height above the loop plane. For a 6.8m loop, a 1.7m height gives a 0.25 height-to-loop dimension ratio and the current multiplier is about 1.4. For the 0.5m height, the ratio against the loop dimension is very close to 0.1 and the multiplier is very close to 1.

A 1.4 variation in field strength corresponds to a 3dB change. Taking the log of 1.4 and multiplying by 20 calculates this. So for the 6.8m square loop; if the loop current is set so the signal strength is correct at the 1.7m height, then the field strength will increase by 3dB at the 0.5m height due to the closer proximity to the loop. If the loop field strength is set for correct level at 0.5m, then the strength will drop by 3dB at 1.7m in height.

The calculation shows that a 6.8m square loop is the smallest sized loop that will provide only a 3dB change in field strength level between the two expected minimum and maximum heights above the loop.

Smaller loops will have a wider variation, while larger loops will have less variation. If you are after minimal variation in field strength with height changes, use a larger loop. A 10m loop, for example, will show less than 3dB variation with a 2m change in listening height.

Note that the extra power requirements for the amplifier are very high when the listening height above or below the loop is significant compared to loop size. For example, if you are using a 2m loop and are 1m above the loop, then the 0.5 height-to-loop ratio shows a loop-current requirement of 2.8 times higher compared to directly along the loop plane. Power requirements are then eight times more (2.8 squared). This also means that a 2m square loop is impractical because the listener must remain fixed at the one height. otherwise the signal level will vary too much.

When you have decided on a loop dimension, use Table.1 to read off the nearest wire size and length requirement to make a 4Ω load. You might require extra wire if the amplifier is not located close to the loop. Note that the table

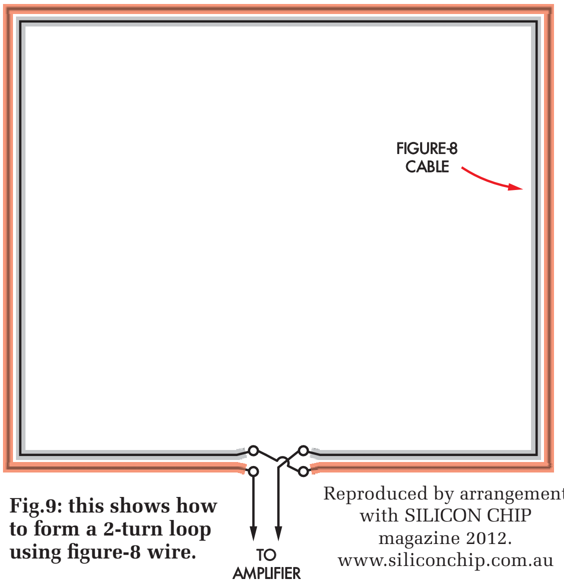


Fig.9: this shows how to form a 2-turn loop using figure-8 wire.

only shows figure-8 wire length. Figure-8 wire comprises two insulated and parallel running wires and when connected to make a single length of wire will form a 2-turn loop (see Fig.9).

Two-turn loop

We show only figure-8 wire in the table because interestingly, a 2-turn loop is the only practical option for an induction loop that is driven using a voltage amplifier. It works out that a 2-turn loop that provides a 4Ω load will have the correct current rating to prevent overheating the loop wire.

This applies even with the extra current requirement for loop monitoring at 1.7m above or below the loop. Using a single-turn loop requires twice the current for the 100mA/m field strength and is likely to overheat the loop wire, making it impractical.

Using more than two turns is not recommended because of loop inductance, which increases by the square of the number of turns. So while two turns produces four times the inductance of a single-turn loop, a four-turn loop will have 16 times the inductance.

Higher inductance means that the amplifier (whether a current or voltage type) needs to be able to provide much more voltage drive at higher frequencies. More details about this inductance effect are provided later.

Table 1 has values of wire resistance calculated based on copper resistance at 0.017241Ω mm^2/m at 20°C. The cross sectional area is the radius of the wire squared times pi (π). For wire with more than one strand, the area for one strand is multiplied by the number of strands. The ohms/metre value was obtained by dividing the total cross sectional area into 0.017241Ω mm^2/m.

Power requirments

The power requirement for a given loop size is calculated using the required current to produce the 100mA/m field and multiplying this by four to get the current for the 400mA peak. For a 2-turn loop, divide this value by two. Overall, this simplifies to multiplying the current for the 100mA/m field by two. The value is then squared and multiplied by the resistance (4Ω) to obtain the power requirement.

Chances are that the loop you are using will not be exactly one of the loop sizes listed in the table. For an in-between value loop size, use the next lowest listed loop size wire gauge. This will mean that the resistance will be higher than 4Ω due to the extra length for the larger loop. Amplifier power requirements may need to be higher if the rated power of the amplifier you are using is close to the amount of power required.

To simplify calculations, Fig.10 shows amplifier power requirements for a 2-turn 4Ω loop of various sizes. One graph shows power required for directly at the loop plane, and the second for 1.7m above (or below) the plane. The power requirements take into consideration the 400mA/m field strength produced during signal peaks. As mentioned, if the loop is more than 4Ω, power requirements will need to be increased by the same ratio. So an 8Ω loop will require double the power. There is no problem using an amplifier that has more power than is required.

For a loop of 15m and larger, the power requirements for along the plane and 1.7m are almost the same. This means that the field strength in the loop effectively does not vary over a 1.7m range. As a consequence, any change in listening height above the plane of the loop will not be subject to variation in signal level. In practice, 10m square loops also do not appear to have any noticeable signal level change with normal variations in height.

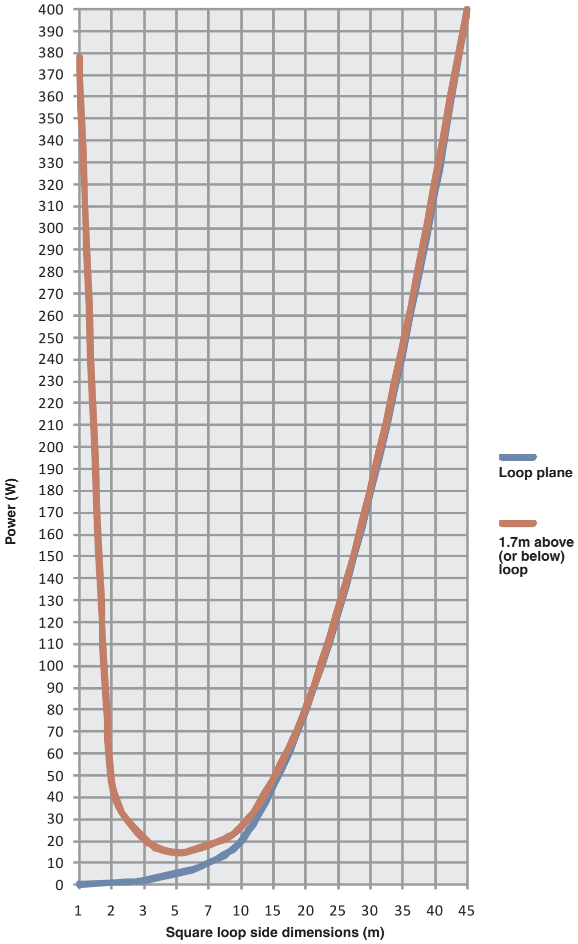


Fig.10: amplifier power requirements when driving a 2-turn 4Ω loop of various sizes. Power is shown for directly along the loop plane and 1.7m above (or below) the plane.

What voltage amplifiers are suitable?

A voltage amplifier for the loop designs described here needs to be able to drive a 4Ω load and it must be unconditionally stable. This is important, because we do not want the amplifier oscillating at a very high frequency and radiating radio frequencies. In addition, the amplifier would produce lots of distortion if it is prone to oscillation.

While many commercially made amplifiers could be used, Table 2 shows some of the more recent and suitable amplifiers that *Silicon Chip / EPE* has published. The table indicates the recommended loop size that could be used with each.

The amplifier power requirement for the loop size takes into account the fact that the loop will be about 1.7m away

from the listening position. See www.jaycar.com.au and www.altronics.com.au for kits.

Loop inductance

We mentioned that loop inductance was a concern because it reduces the amount of current that is applied to the loop as frequency increases. Hence, treble boost is needed.

Australian Standard AS60118.4-2007 recommends that the frequency response of the magnetic field be 100Hz to 5kHz within ±3dB. Naturally, the response can cover a wider range of frequencies. In practice though, having rolloff above 5kHz is ideal because it removes the need for excessive treble boost.

We plotted loop inductance versus loop size and this can be seen in the graph of Fig.12. Inductance of a square, rectangular or circular loop can be calculated using an inductance calculator.

We used the calculator at www.technick.net/public/code/cp_dpage.php?aiocp_dp=util_inductance_calculator

For the purpose of this exercise, inductance calculation was based on 1mm diameter wire (0.5mm radius). The µ value for air is 1. Inductance is shown for both a single turn loop and using figure-8 wire that forms two turns. Note how the inductance for two turns is four times that of one turn. The inductance values are based on a square loop shape. Rectangular loop inductance can be calculated using the rectangular shape option in the above mentioned inductance calculator.

Typically, a rectangular loop will have the same inductance as a square loop that has the same wire length. For example a 10m square loop has the same inductance as a 15 × 5m rectangular loop.

From the inductance we can calculate the 3dB down rolloff for a 4Ω loop. How this is calculated is described in the section entitled 'Impedance of the loop'. A simplified calculation for 4Ω loops is that the –3dB frequency = 0.6366/inductance (in henries). Multiply the –3dB frequency by two for 8Ω loops.

Rolloff frequency

The graph in Fig.13 shows the –3dB rolloff frequency against loop side length. The graph reveals that for a 2-turn loop, the frequency response is no more than 3dB down at 5kHz for square loops up to almost 5m. Larger loops will require treble boost to compensate for the rolloff.

Actual rolloff against frequency for various sized loops is shown in the Fig.14 graph. For the 5m square loop, rolloff is just over 3dB down at 5kHz, but for a 20m square loop rolloff is –14dB down.

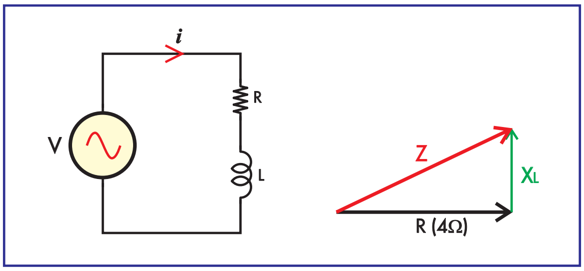


Fig.11: the total impedance of a series-connected resistor and inductor is calculated using a phasor diagram. Impedance of the resistor is *R* and reactance of the inductor is X_L. Total impedance is *Z*.

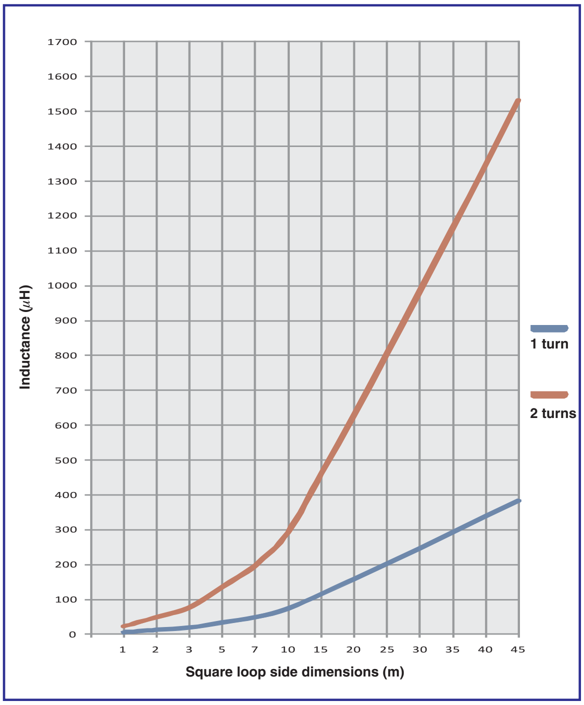


Fig.12: the plot of loop inductance versus loop size. The graph shows inductance for both 1-turn and 2-turn loops. Note how inductance is four times greater in the 2-turn loop. Typically, a rectangular loop will have the same inductance as a square loop that has the same wire length.

The *Hearing Loop Amplifier* signal pre-conditioner, that we will describe in a later issue, has treble boost compensation to correct for these rolloffs.

Note that adding treble boost to an amplifier's signal input might appear to mean that extra power will be required from the amplifier.

However, extra amplifier power is not normally required because the power requirement for reproducing naturally occurring sounds becomes less at higher frequencies. Typically, natural sounds have the same energy per octave. And so, while there are four octaves between 100Hz and 1600Hz there are less than two octaves between 1600Hz and 5kHz. Treble boost is only applied from about 1600Hz through to 6kHz.

For large loops (15m square and over), a fair degree of treble boost is necessary. In these cases it may be best to use a slightly higher powered amplifier than one selected from the design graph and tables, especially if the power available from the amplifier is only just sufficient for the size of the loop. It is not practical to compensate for treble loss for loops larger than 20m square.

Impedance of the loop

A hearing loop generally comprises a wire length in the shape of a rectangle or square. The impedance of the loop comprises the resistance of the wire plus the (X_L) reactance due to the inductance (L) of the loop. These two components are effectively in series. The loop resistance will remain reasonably constant, although it will vary with temperature. The main variation in the loop will be due to the reactance that rises with frequency.

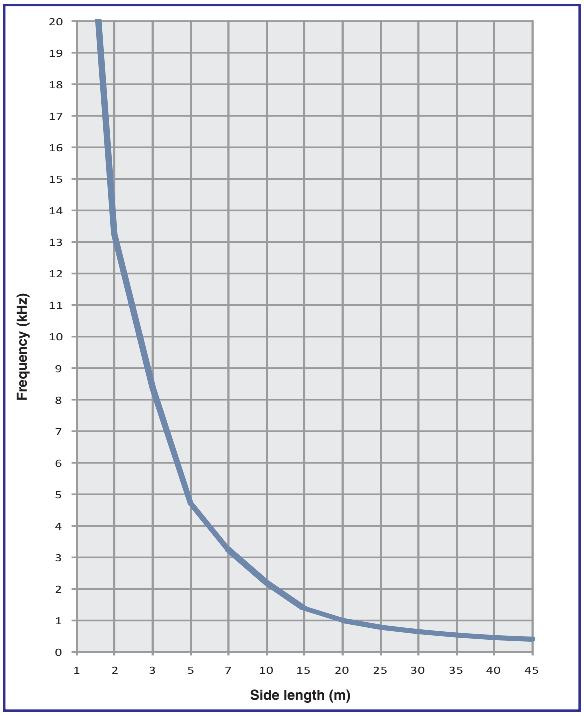


Fig.13: this shows the –3dB rolloff frequency with various loop side lengths (4Ω, two turns). Frequency response varies by no more than 3dB up to 5kHz for loops no larger than 5m square. Larger loops will require treble boost to compensate for the rolloff before 5kHz.

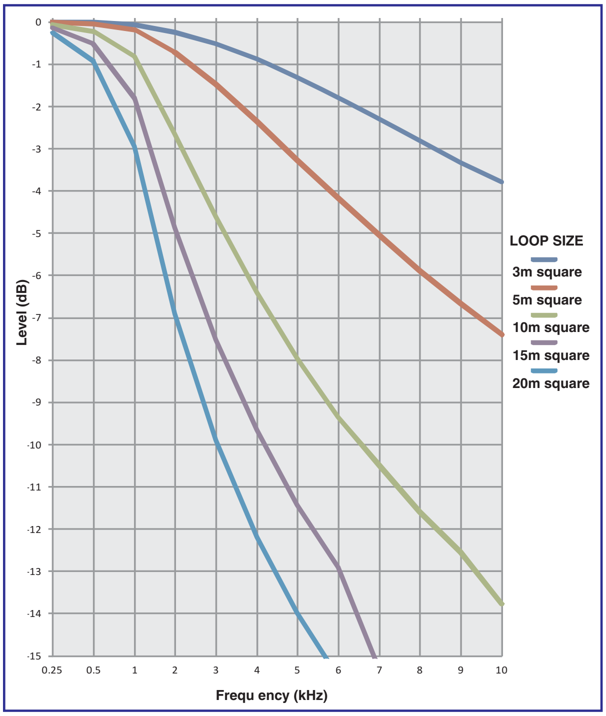


Fig.14: frequency response for various sized loops (4Ω, two turns). For a 5m square loop, rolloff is just over 3dB down at 5kHz, but for a 20m square loop rolloff is –14dB down. Typically, a rectangular loop will have the same response and –3dB rolloff as a square loop with the same wire length.

A pure resistance without inductance has a current that is in phase with the voltage. For a pure inductor, which has no resistance, the current lags the voltage by 90°. Its reactance is given by:

$X_L = 2 \times \pi \times$ frequency × the inductance.

To find the total impedance effect of both the resistance and the reactance of the inductor we need to consider the two quantities as shown in the phasor diagram of Fig.11.

Resistance is shown as R and the reactance (X_L) is 90° different in phase. To add the two values we square both the R value and the X_L value, add the two squared values, and then take the square root of the sum. This gives the value of the impedance (Z). Mathematically, this is just using Pythagoras' theorem to calculate the length of the hypoteneuse in a right-angled triangle.

Assuming the resistance R is 4Ω, at low frequencies the impedance of the inductor is low and so the overall impedance is close to 4Ω. As frequency rises, the impedance of the inductor rises and begins to have a greater effect on the overall impedance of the loop.

The rising impedance has an effect on the current flow within the loop. If an amplifier is fed with a constant voltage level, the current will reduce as frequency rises as

Table 2: SILICON CHIP / EPE amplifier data

Power into 4Ω	Loop size	Amplifier Name	Silicon Chip/EPE publication date	Kit supplier No.
20W	3-8m square	Compact High Performance 12V Stereo Amplifier	May 2010 / 2012	Jaycar KC5495, Altronics K5136
30W	2.5-11m square	Schoolies Amplifier	December 2004	Altronics K5116
55W	2-16m square	50W Audio Amplifier Module	March 1994	Jaycar KC5150, Altronics K5114
70W	2-18m square	SC480	January 2003	Altronics K5120
200W	1.5-33m square	Ultra-LD Mk2	August 2008 / 2010	Jaycar KC5470, Altronics K5151
350W	Up to 42m square	Studio 350 Power Amplifier	January 2004	Jaycar KC5372

This shows some of the more recent and suitable loop driving amplifiers published in *Silicon Chip* and *EPE*, ranging from 20W through to 350W. The table also shows the recommended size of loop that should be used with each.

the impedance increases. The loop current is the voltage divided by the impedance.

At low frequencies, the reactance X_L is close to zero, and so the 4Ω resistance mainly sets loop current. As the frequency rises, the reactance increases, the total impedance rises and so current drops. The –3dB down frequency is when the resistance R is equal to the reactance X_L. Then the current is 0.7071 of the DC current.

As an example (and using simple numbers), lets say R is 1Ω and voltage is 1V AC. Current I at a low frequency is 1A. When the AC frequency is higher, the reactance of the inductor will be 1Ω at a specific frequency depending on the inductance. The impedance Z becomes the square root of 2 or 1.414Ω. So the current is 1/1.414 or 0.7071 in value. This reduction to 0.7071A compared to the original 1A is the –3dB level.

A hearing loop does not use radio!

A common misconception with hearing loops is that they operate using radio waves. In other words, it is assumed that the loop acts as a radio antenna and the hearing aid includes a wireless receiver for reception. This is not true.

The magnetic field from the loop is simply modulated at the audio signal frequency at up to around 5kHz.

While the magnetic field produced by the loop is a part of the electromagnetic spectrum, its properties are unlike radio waves. For example, the wavelength at 3kHz is very long, at around 100km, compared to radio waves that start at around 300m.

In the same way, the electromagnetic fields produced by 50Hz power lines are not considered to be radio waves. Other examples of waves that are also part of the electromagnetic field spectrum include infrared radiation (heat), visible light, ultra-violet light (UV) and X-rays. These too are not considered radio.

Health effects using a hearing loop?

While it is certain that some electromagnetic fields can cause detrimental health effects (eg, UV and X-rays), it is unclear whether the low frequency and low level magnetic field from a hearing aid will have any detrimental effect. Most research concerning the effects on cells with electromagnetic radiation is concentrated on 50Hz power transmission, along with the higher frequencies such as microwaves, X rays, and ultra-violet radiation.

Mobile phones come under the microwave category and operate at around 3GHz. The microwave energy from a mobile phone is vastly higher than that from a hearing loop and its frequency is at least one million times greater, and with much higher energy.

There is no correlation between the effects of microwave energy causing cell damage in the body and any effects caused by hearing loops.

If we consider the 50Hz power line frequency as being the closest studied radiation compared to the hearing loop, the recommended maximum continuous exposure to magnetic field is 0.1mT (millitesla). This data was obtained from the Australian Radiation Protection and Nuclear Safety Agency. (www.arpansa.gov.au/radiationprotection/facsheets/is_emf.cfm).

The recommended magnetic field strength in audio-frequency induction loops for hearing aid purposes is 100mA/m at 1kHz, rising to 400mA/m during peaks, which equates to 0.126μT and 0.5μT respectively – more than 1000 times less than the 0.1mT level.

Magnetic field strength

For the hearing loop specifications, magnetic field strength is expressed using the units of A/m or amperes per metre. The letter H is used to label this field. The field represents the total amount of field strength provided by the loop.

Another way of expressing a magnetic field is with the letter B, which is the magnetic field density and describes how the field is concentrated due to the medium within the field. Its units are in tesla (T). The field medium can be free space (usually air) or it can be other materials such as iron or ferrite. These latter mediums distort the magnetic field with higher concentrations found within the iron or ferrite.

Where a hearing loop is installed and there is significant steel in the field, then available field strength in the free space (air) will be reduced because the field will be concentrated through the steel. The hearing loop needs to be driven with more power to counteract the loss within the steel.

The H field strength values and the B magnetic field density values are easily converted from one to the other using the equation $B=\mu H$. B is the magnetic flux density (T) and μ is the permeability of the magnetic field medium. This is $4 \times \pi \times 10^{-7}$ for air and free space.

For a hearing loop, the 100mA/m field strength produces a field density of 0.126μT. The 400mA/m level is 0.5μT.

By the way, if you prefer to use gauss (G) units instead of tesla, the conversion is 0.1μT=1mG. So 0.126µT is 1.26mG.

An under-floor hearing loop installation. Unfortunately, under-floor access is rarely this good. Special considerations also apply if the floor is steel-reinforced concrete; indeed under-floor loops may not be possible

Next month

We'll continue our look at hearing loops, examining some of the commercial equipment available.

This receiver is designed to pick up the signal from a hearing loop and will drive a pair of headphones. You can use it with a hearing loop you install in your own home or with commercial loops already installed in halls and churches.

HEARING LOOP RECEIVER

By JOHN CLARKE

ELSEWHERE in this issue, we introduce the concept of hearing loops for those with hearing loss. They're specifically intended for use with hearing aids fitted with T-coils (the other article explains T-coils).

But there are many people in the community who have hearing loss and, for various reasons (cost, denial and self-consciousness) don't own or want a hearing aid, particularly one of the more advanced types.

This project, in fact the whole series of related projects, is intended for them or anyone else who 'suffers in silence'.

You might have experienced it in your own household: someone who wants the TV or stereo turned up beyond everyone else's comfort level so they can hear it.

Connect a hearing loop to your TV or stereo system, use this *Hearing Loop Receiver* and an earbud or two – and they will be able to hear everything in the programme, with no need to have the volume cranked up.

Loop receiver

Our *Hearing Loop Receiver* is housed in a small case which can attach to a belt or be slipped into a pocket, so it's fully self-contained. The user can walk around without the sudden jolt of reaching the end of a headphone lead! It's equipped with a power switch, power on LED, volume control and, of course, a standard 3.5mm jack outlet for headphones or earphones.

Specifications

Current consumption 10mA

Frequency response........... –3dB at 100Hz with stereo 32Ω headphones connected. Upper response to beyond 5kHz

Signal-to-noise ratio .... –67dB A-weighted with respect to a 400mA/m (field strength and VR1 at mid setting with stereo 32Ω headphones connected). Noise is dependent upon background environmental noise from mains wiring and equipment

Battery volt indication....... down to 7V

Current consumption is about 10mA, which should give up to 40 hours of use before the 9V battery needs to be changed (a rechargeable battery could be used). The power LED also functions as a battery indicator, where its initial brightness when power is applied is dependent upon battery voltage.

By now, we hope you've read the introductory article in this issue on the design and installation of a hearing loop. That will give you a much better understanding of how the *Hearing Loop Receiver* works, so we won't go into a lot of detail here.

But if you haven't read that article, a hearing loop at its most basic simply consists of a loop of wire around a room, driven by a standard audio amplifier. The magnetic field it produces induces the audio signal into a coil in a hearing aid equipped with a T-coil or in this case, our receiver.

It's all housed inside a 'remote control' case, which is small enough to fit into a pocket, or clip to a belt via an optional clip. So, if you forget you're wearing it and get up to walk around, you won't leave your head in your easy chair

Circuit description

The full circuit digram for the *Hearing Loop Receiver* is shown in Fig.1. It comprises two low-cost ICs plus a handful of other cheap parts.

The magnetic field from the 'hearing loop' is detected using inductor L1. This is actually the secondary winding of a standard Xenon flash tube trigger transformer (eg, Jaycar MM2520). Because of the very large number of turns, it has a high inductance – around 8.2mH. Best of all, it is quite cheap and is suitable for the task of hearing loop monitoring.

One side of L1 is biased at about +4.05V using two 10kΩ resistors connected in series across the 8.1V supply. A 100µF capacitor bypasses this half-supply. The 4.05V rail biases the output of IC1b so that its output can swing symmetrically within the available power supply rail.

Tying one side of the transformer secondary winding to the +4.05V supply means that it is effectively grounded, while the other end of the winding provides the signal to op amp IC1b. The DC resistance of inductor L1 is 27Ω, presenting a low source impedance at low frequencies to the non-inverting input of IC1b, thereby minimising low-frequency noise.

A 2.2kΩ resistor is connected in parallel with L1 to lower the inductor's Q and prevent the possibility of oscillation. The 220pF capacitor that shunts high frequency signals to ground also assists in this. Furthermore, the input of each amp stage has a 10Ω 'stopper' resistor to help prevent oscillation.

Any signal induced in L1 will rise in level with frequency, at about 6dB per octave, because the induced voltage is proportional to the rate of change of the magnetic field.

To compensate for this and to provide a flat frequency response, a 33nF capacitor across the 100kΩ feedback resistor, between pin 6 and pin 7 of IC1b, rolls off the signal above about 50Hz at 6dB/octave. This counteracts the rise in response from the inductor. At the same time, the frequency response is rolled off below 16Hz using the series connected 1kΩ resistor and 10µF capacitor between pin 6 and ground.

Op amp IC1a provides the second stage of gain, adjustable via the 10kΩ trimpot, VR1. In the trimpot's minimum position, the maximum gain is 101, as set by the 100kΩ and 1kΩ resistors. Minimum gain of about 10 is available when VR1 is set at maximum. Because of VR1, the low frequency rolloff at maximum gain is 16Hz (the same as for IC1b) and 1.45Hz at minimum gain.

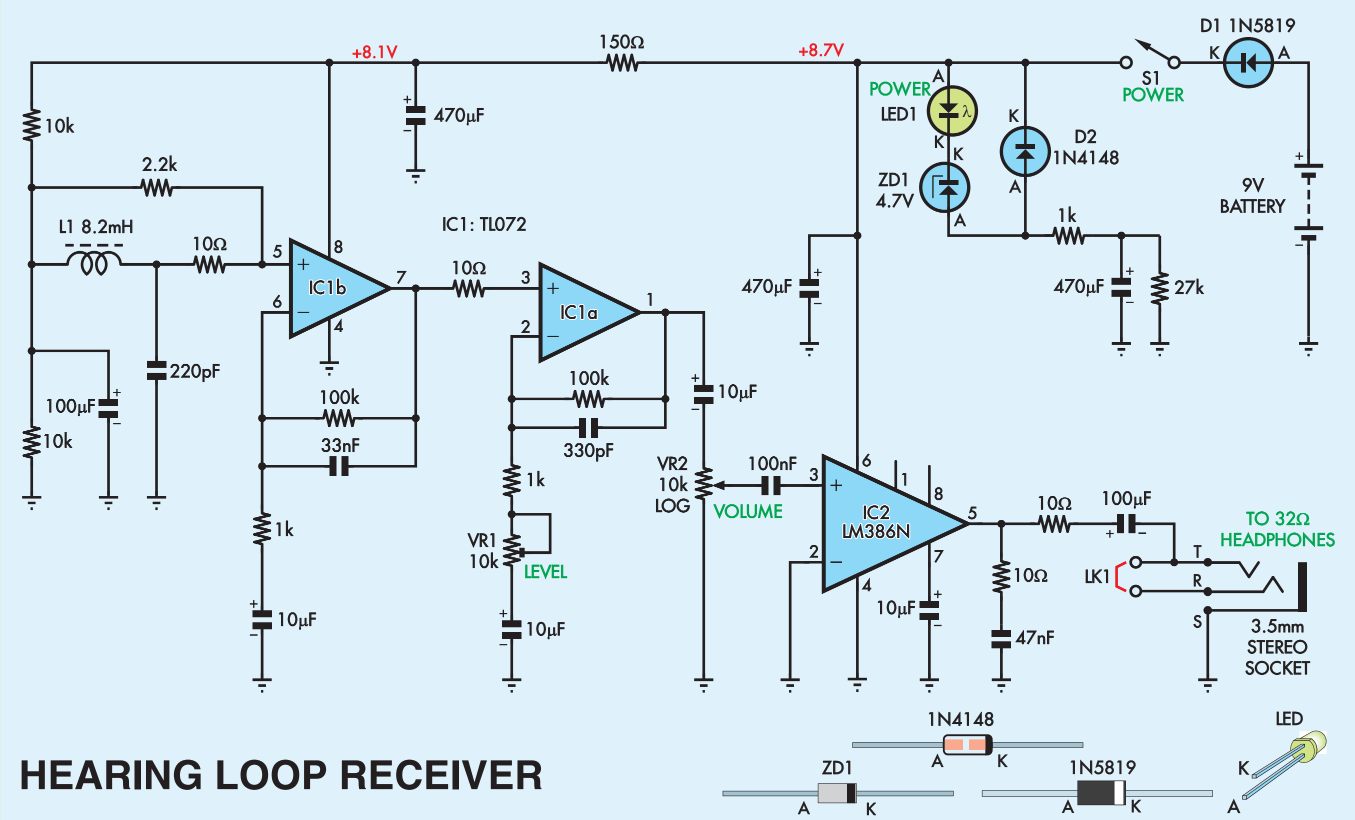


Fig.1: the electromagnetic signal radiated by the hearing loop in the building is 'intercepted' by inductor L1, which is then amplified and processed by IC1 before being fed to audio amplifier IC2, which drives the headphones.

Further frequency rolloff is provided by the 330pF capacitor across the 100kΩ feedback resistor. This rolls off signals above about 4.8kHz.

Next, the signal passes through a 10µF coupling capacitor to the 10kΩ volume control, VR2. This sets the level of the signal applied to the LM386 audio power amplifier, IC2. This can provide up to about 500mW into 8Ω with a 9V supply, with distortion typically 0.2%.

When using stereo 32Ω headphones, the power is about 250mW; more than adequate for headphone listening. Note that both left and right headphones are connected in parallel, via link LK1.

IC2 has a gain of 20, and its power supply is bypassed with a 470µF capacitor. The separate 10µF bypass at pin 7 removes supply ripple from the amplifier's input stages.

Controls are simple: just a power switch and volume. Most 3.5mm phones/ear buds will be fine. The large 'block' at the back of the case is an optional belt clip so the unit can easily be worn around the waist.

A Zobel network comprising a series 10Ω resistor and 47nF capacitor prevents amplifier instability.

The LM386 drives the headphones via a 10Ω resistor and 100µF capacitor. The 100µF capacitor provides low frequency rolloff below 61Hz, assuming that 32Ω stereo headphones are used.

The circuit is powered by a 9V battery, while diode D1 provides protection against reverse polarity connection (which is quite easy to do with a 9V battery).

LED battery condition indicator

LED1 functions as a battery condition indicator, as well as showing when the *Hearing Loop Receiver* is on.

When power is first applied, current for the LED flows through the 4.7V Zener diode ZD1, the 1kΩ resistor and the discharged 470µF capacitor.

If the battery is fresh, the 9V battery provides 8.7V at the anode of LED1. This voltage is reduced by about 1.8V by LED1 and by 4.7V with ZD1, leaving 2.2V across the 1kΩ resistor. So LED1 lights with a current of 2.2mA.

At lower battery voltages, there is less voltage across the 1kΩ resistor, so the LED is dimmer. At a battery voltage of 7V, there is about 0.2V across the 1kΩ resistor and the LED barely lights.

With LED current flow, the 470µF capacitor charges up so that the LED current is reduced. A 27kΩ resistor across the 470µF capacitor ensures that the LED stays lit, but at a low current that allows it to be still visible. This indicates that the power is on and means that battery voltage testing happens only at power up. When the receiver is switched

off, diode D2 discharges the 470µF capacitor.

The 8.7V supply is used directly by IC2, but it is fed to IC1 via a 150Ω resistor. A 470µF capacitor decouples this supply and prevents any supply modulation from affecting IC1, which could cause instability.

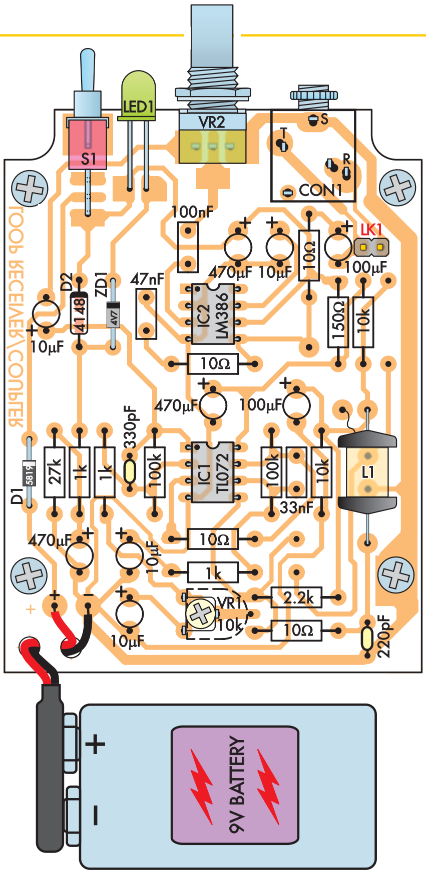
Construction

The *Hearing Loop Receiver* is constructed on a PC board measuring just 65mm × 86mm. This board is available from the *EPE PCB Service*, code 865. The component layout is shown in Fig.2.

The PC board and components are housed in a 'remote control' case measuring 135mm × 70mm × 24mm. Panel labels attach to the front edge of the box and on the front face.

The PC board is designed to fit on to the mounting bushes within the box. Make sure the front edge of the PC board is shaped to the correct outline so it fits into the box. It can be filed to shape if necessary using the PC board outline shape as a guide.

This PC board can also be used to build the *Hearing Loop Neck Loop Coupler* (which we will describe in a future issue) since most of the parts are the same. However, there will be a few unused component holes in the PC board for the *Hearing Loop Receiver*.



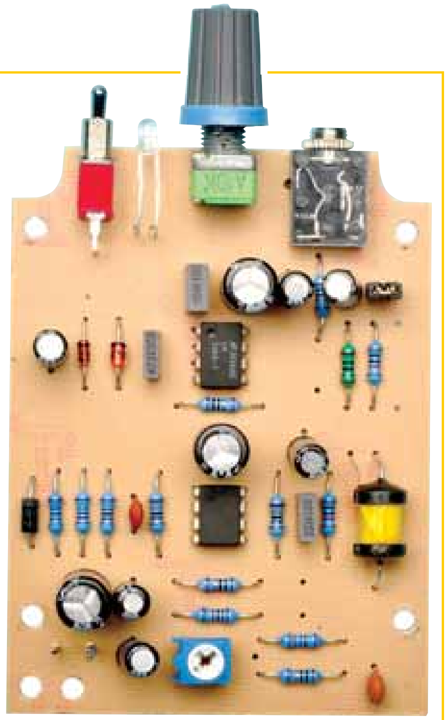


Fig.2 (above left) shows the component layout on the PC board, with a matching photo alongside. Ignore the unused holes in the board – they're for another project in the series. The photo below shows how it all fits together inside the case.

Board assembly

Begin construction by checking the PC board for breaks in copper tracks or shorts between tracks and pads. Repair if necessary. Check the hole size for the PC board mounting and for the 9V battery leads. These are 3mm in diameter.

Assembly can begin by soldering in the two PC stakes, followed by the resistors. Use the resistor colour code table and/or a digital multimeter to help in confirming the resistor values. The diodes can now be installed, mounted with the orientation shown.

IC1 and IC2 can be now be installed, either directly on the PC board or mounted on 8-pin IC sockets (which makes removal easier if necessary). When installing sockets or ICs, orient them using the notch positioned as shown.

Install the 2-way header (LK1), followed by the capacitors. Make sure the capacitors are placed on the PC board so their height above the board is no more than 12.5mm, otherwise the lid of the case will not fit correctly. Electrolytic types must be oriented with the shown polarity.

Trimpot VR1 and inductor L1 are next. Note the third wire of L1 is soldered to a spare pad on the PC board. Switch S1, potentiometer VR2 and the 3.5mm stereo socket can be soldered in next.

LED1 mounts horizontally, but at a height of 6mm above the PC board. Bend its leads down 90°, 12mm from the base

Fig.3 (right) the front panel label, reproduced here same size, depicts the hearing loop symbol. It was adapted from the international 'hearing assistance' symbol (with the added 'T'). It is displayed wherever a hearing loop is installed. In many cases, there will also be raised Braille dots giving the same message to blind people.

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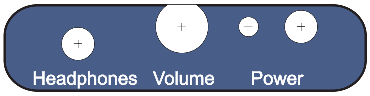


Fig.4: this label is glued to the top panel of the receiver case

of the LED, making sure the anode lead is to the left.

To install the 9V battery clip, firstly pass the wires through from the battery compartment side of the case and loop the wires through the holes in the PC board. This secures the wires, ready to be soldered to the PC stakes.

Four 6mm M3 screws secure the PC board to the integral mounting bushes in the box. However, before fitting, you need to drill out the small holes for the switch, LED, volume pot and headphone socket in the top panel – see Fig.4. A 1:1 photocopy of the label makes a good template for drill hole positions.

You can also colour photocopy the top (Fig.4) and front panel (Fig.3) labels. You could use adhesive-backed paper, or plastic film such as, overhead projector film. You can use clear tape, or silicone sealant/varnish to protect the lettering on the film. Likewise, you could also laminate the paper copy. Another alternative would be to scan Fig.3. and Fig.4, and 'play around' with your computer to produce your own custom designed panels.

The plastic film can be glued to the panel using an even smear of neutral-cure silicone. If you are using a black panel, use coloured silicone, such as grey or white, so the label has contrast. For panels that are off white or aluminium, use clear silicone sealant.

Cut the holes out in the panel using a sharp hobby knife.

Testing

Apply power and check that the power LED lights. There should be about 8.1V between pins 4 and 8 of IC1 (assuming a 9V battery supply). IC2 should have about 8.7V between pins 4 and 6.

If these tests are OK, plug in a pair of headphones and apply the 'blurt' test: touch the inductor (L1) terminal on the lower section of the PC board. There should be a 'blurt' noise in the headphones if the volume is turned up.

Final testing can be made with the *Hearing Loop Receiver* and a hearing loop. Note that the receiver needs to be at right angles to the loop, ie, for a normal horizontally mounted loop, the receiver is held vertical. Trimpot VR1 is adjusted so that the volume range for VR2 is suitable without allowing the volume level to be adjusted to excessive levels. ***EPE***

Parts List – Hearing Loop Receiver

1 PC board, code 865, available from the *EPE PCB Service*, size 65mm × 86mm
1 'remote control' case, size 135mm × 70mm × 24mm (Jaycar HB5610 or equivalent)
1 top panel label 55mm × 14mm
1 front panel label 75mm × 49mm
1 miniature SPDT toggle switch, PC mount (S1)
1 3.5mm stereo socket, PC mount
1 knob to suit potentiometer
2 8-pin IC sockets (optional)
1 trigger transformer for Xenon flashtube (L1) (Jaycar MM2520, or equivalent)
4 M3 × 6mm screws
1 2-way pin header with 2.54mm spacing
1 jumper shunt
1 9V (216) alkaline battery
1 9V battery clip, with leads
2 PC stakes

Semiconductors

1 TL072 dual op amp (IC1)
1 LM386 1W amplifier (IC2)
1 4.7V 1W Zener diode (ZD1)
1 3mm LED (LED1)
1 1N5819 1A Schottky diode (D1)
1 1N4148 switching diode (D2)

Capacitors

3 470µF 16V PC electrolytic
2 100µF 16V PC electrolytic
4 10µF 16V PC electrolytic
1 100nF MKT polyester
1 47nF MKT polyester
1 33nF MKT polyester
1 330pF ceramic
1 220pF ceramic

Resistors (0.25W, 1%)

2 100kΩ 1 27kΩ 2 10kΩ
1 2.2kΩ 3 1kΩ 1 150Ω
4 10Ω
1 10kΩ horizontal trimpot (VR1)
1 10kΩ log potentiometer, 9mm square, PC mount (VR2)

Resistor Colour Codes

	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❑	2	100kΩ	brown black yellow brown	brown black black orange brown
❑	1	27kΩ	red violet orange brown	red violet black red brown
❑	2	10kΩ	brown black orange brown	brown black black red brown
❑	1	2.2kΩ	red red red brown	red red black brown brown
❑	3	1kΩ	brown black red brown	brown black black brown brown
❑	1	150Ω	brown green brown brown	brown green black black brown
❑	4	10Ω	brown black black brown	brown black black gold brown

Mark Nelson

The threat in your pocket

If you thought that viruses affected only computers, think again! Smartphones are now being targeted by pernicious malware, while all types of mobile handset are also under attack. Time to get wise to these perils, reckons Mark.

I CHOSE this melodramatic title deliberately in the hope of catching your attention. Thanks for obliging me, for it's no joke.

Remember how Mac owners used to boast to PC users that they had no need for antivirus software because no-one wrote malware for Macs? These days it's reported that one-in-five Mac systems is infected. Although most of these viruses (or viri?) are intended to be passed on to PC users and do not run in OS X, according to respected antivirus vendor Sophos, one-in-thirty six Mac systems is infected with true OS X-based malware.

I mention this because people used to scoff when the existence of malware for mobile phone users was being discussed. When handsets had very restricted processing capability, this reaction may have been justified, but now, when some smartphones are more powerful than desktop PCs and smartphone sales have overtaken shipments of PCs, it's time to think again.

Mobile phones under attack

Symantec, another antivirus vendor, also warns in its 2012 Internet security threat report. While computer malware remains a high risk to users without antivirus protection, mobile devices offer lucrative new opportunities to cybercriminals. According to Symantec, stolen credit card numbers can net peddlers as little as 25p to 50p, but bogus text messages can earn their authors £6 for each text. Private or corporate victims who do not watch their phone bill could make this a highly rewarding opportunity for these cybercriminals.

'With the number of vulnerabilities in the mobile space rising and malware authors not only reinventing existing malware for mobile devices, but also creating mobile-specific malware geared to the unique opportunities mobiles present, 2011 was the first year that mobile malware presented a tangible threat to enterprises and consumers,' attests the company.

Rival firm McAfee adds further colour to this story. In the first quarter of 2012, it noted a large increase in mobile malware, targeted almost solely at the Android platform. Android threats now reach almost 7,000 from more than 8,000 total mobile malware viruses in McAfee's database. The firm advises Android users to use apps only from the official market, as the great majority of infected apps (and mobile attacks) stem from unofficial third-party vendors, particularly in China and Russia.

Unwanted wares and worse

The mildest form of dodgy apps do not necessarily compromise users' security, but subjects them to unwanted wares, ranging from wallpaper with added sales pitches to fake versions of games that send visitors to advertising sites. Some malware causes mischief or damage in a way that appears to amuse the author, such as altering the wallpaper of the infected iPhone or sending anti-religion text messages through Android phones.

The real threat lies in stealth software that sends information from the phone to sites under the control of the attacker. This then sends out text messages to premium-rate numbers, with the attacker's control server updating the message body and the number the hijacked phone sends to.

This year, McAfee detected one of the first destructive Android trojans, which searches for photos stored on the SD card, and adds the image of Ayatollah Khomeini to each picture until there is no more space on the card. The message is clear: users must protect all devices, mobile or otherwise, that store valuable data. If not, today's cybercriminals will be happy to handle it for them.

Unbiased report

If you think antivirus firms might have an axe to grind, maybe an independent analysis would be more welcome. A report published by the University of California distinguishes three types of threats: malware, grayware, and personal spyware. Malware gains access to a device for the purpose of stealing data, damaging the device, or annoying the user and so on.

Grayware spies on users, collecting data for commercial purposes, without aiming to harm users (if that's any consolation). Personal spyware sends the victim's information to the person who installed the application on to the target's device, rather than to the author of the application.

To avoid contagion from mobile malware, smartphone users are encouraged to download and purchase apps from officially-recognised application markets, such as those run by Apple, Google, and Nokia. According to the report, the Apple App Store is known to have included grayware, although in some cases the grayware has been removed from the App Store. Personal spyware and grayware are or were listed in the Android Market, but the Android security team removed malware following user complaints.

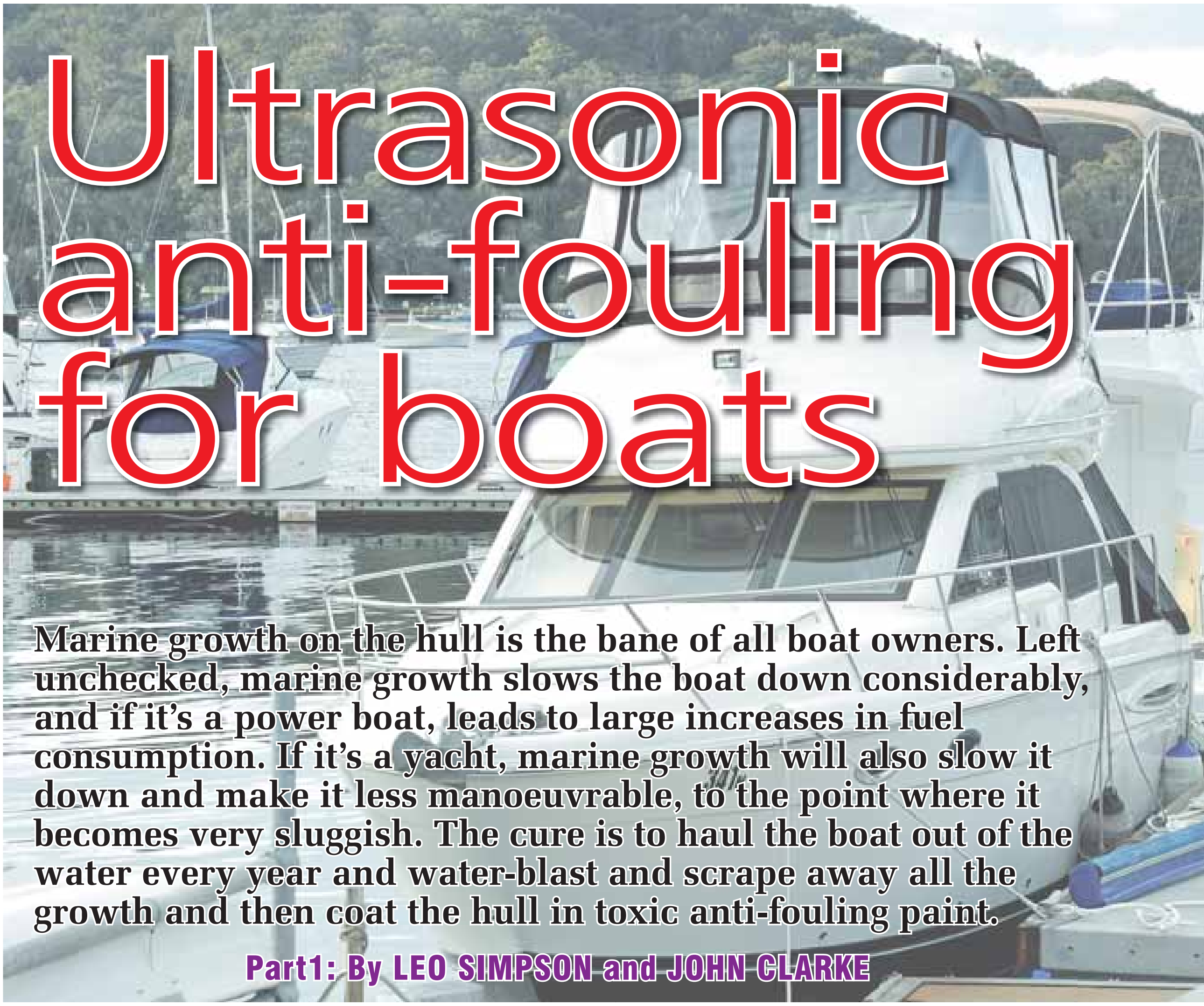
The report's writers elaborate: 'Three pieces of malware target user credentials by intercepting text messages to capture bank account [log-in] credentials, mounting sophisticated attacks against two-factor authentication. Another piece of malware launches a phishing attack on the phone. Phishing attacks can be more convincing on phones than in a desktop browser, and we expect to see more phishing attacks from mobile malware in the future.'

Botnet burden

If this were not bad enough, there is convincing evidence that botnets for mobile devices are now a reality. Botnets, as you will recall, are collections of compromised computers, each known as a 'bot', connected to the Internet. The computers have come under the control of the 'botmaster' or 'bot herder', who uses the infected computers to spew out spam or commit denial-of-service attacks.

The first mobile botnet was reported in 2009, with malware such as DroidDream, Geimini and GingerMaster behind the new generation of mobile botnets. This year, one botnet in China alone was generating anywhere between $1,600 to $9,000 per day according to Symantec.

If this has you worried, I suggest you visit **www.moneysavingexpert.com/shopping/free-mobile-antivirus-software** for advice on keeping your mobile device virus-free. Other sources of advice are available of course.



Ultrasonic anti-fouling for boats

Marine growth on the hull is the bane of all boat owners. Left unchecked, marine growth slows the boat down considerably, and if it's a power boat, leads to large increases in fuel consumption. If it's a yacht, marine growth will also slow it down and make it less manoeuvrable, to the point where it becomes very sluggish. The cure is to haul the boat out of the water every year and water-blast and scrape away all the growth and then coat the hull in toxic anti-fouling paint.

Part1: By LEO SIMPSON and JOHN CLARKE

EVERYONE knows that owning and maintaining a boat is expensive; the bigger the boat, the more expensive it is.

Many readers will be familiar with trailer sail-boats and power boats. These are relatively cheap to run and since they are not left in the water, they should never have problems with marine growth. However, once you have a boat on a swing mooring or tied up to a berth in salt water, marine growth is endemic and the warmer the water, the more severe the problem.

The vast majority of larger boats are moored year-round in warm, salty waters and so marine growth is a big problem. In years past, the solution was to coat the hull in an arsenic-based anti-fouling compound, but these were highly toxic to all marine life and have now been banned. This means that the anti-fouling compounds used now, while still toxic to marine growth, are far less effective.

The problem is even more severe for boats that are moored in canal developments, because there the water is warmer and there is little water movement, marine growth can be so rapid that anti-fouling needs to done as often as every six months.

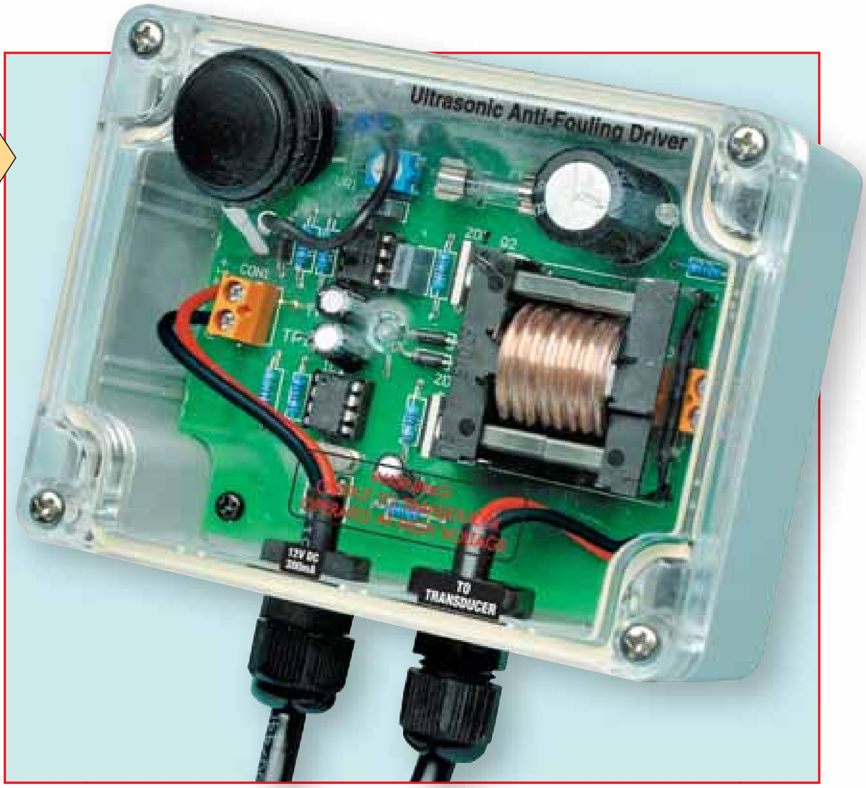
If a boat is not being used, marine growth can still rapidly take hold and there can be significant growth after only a few months. This is because anti-fouling coatings are 'ablative', which means that they depend for their operation on the boat moving through the water to literally wear off the surface and thereby expose fresh (and toxic) anti-fouling compound.

Ultrasonic anti-fouling

So, anti-fouling needs to be done at least once a year and in some cases, more frequently if the boat is seldom used or moored in a canal. If you do this work on your own boat, it is tedious, dirty and expensive (even hauling the boat out of water is expensive). If you pay someone else to do it, it is much more expensive. All boat owners would love to avoid this cost.

Now there is ultrasonic anti-fouling for boats. This electronic method means the end of chemical anti-fouling

Build it and keep the barnacles at bay electronically



The driver circuit is housed in an IP65 type ABS box with a clear lid. It produces the high-voltage pulsed waveform that's used to drive the ultrasonic transducer.

and a big reduction in cost for boat owners. It involves installing a high power piezoelectric transducer inside the boat's hull, and the ultrasonic energy keeps marine growth at bay.

How it works

The way that this works is that the ultrasonic vibration of the hull disrupts the cell structure of algae and this stops algal growth adhering to the hull. And because there is no algal food source on the hull, larger marine organisms have no reason to attach themselves to the hull – no food, no lodgers.

The principles of ultrasonic anti-fouling have been known for a long time. The effect was discovered 80 years ago by French scientist Paul Langevin, who was developing sonar for submarines. By accident, he found that ultrasonic energy killed algae.

He was working with high power transducers and it was assumed that cavitation was causing algal death. In recent times though, it has been found that high ultrasonic power and cavitation is not required to kill algae.

Instead, it has been found that ultrasonic frequencies can cause resonance effects within algal cell structures, and relatively low powers are still enough to cause cell death. So, if the boat's hull can be vibrated over a range of ultrasonic frequencies, algae will not be able to attach to it and other marine growth will similarly be discouraged.

Commercial ultrasonic anti-fouling systems have been available for the last few years, but they are very expensive, costing thousands of pounds to install. There is still a cost benefit though, and these systems are gradually becoming more popular as news of their effectiveness grows.

However, we should state at the outset that the manufacturers do not make blanket guarantees that ultrasonic anti-fouling systems work in every situation. We can understand that.

WARNING!

This circuit produces an output voltage of up to 800V peak-to-peak to drive the ultrasonic transducer and is capable of delivering a severe (or even FATAL) electric shock. DO NOT touch the output terminals at CON2, the PC tracks leading to CON2 or the transducer terminals when power is applied.

To ensure safety, the PC board must be housed in the recommended plastic case, while the transducer must be correctly housed and fully encapsulated in resin, as described in Part 2.

It's this lack of a blanket guarantee that's probably holding back market acceptance. Most boat owners will be very cautious about investing several thousand pounds in a system that may not work in their case. That is where our design will be a game-changer. It will cost a fraction of the price of equivalent commercial systems, yet should have the same effects.

Specifications

Overall output frequency range: from 19.08kHz to 41.66kHz in 14 bands; frequency overlapping included between each band

Frequency sweep in each band: 12 frequencies ranging from approximately 80Hz steps at 20kHz to 344Hz steps at 40kHz

Signal burst period: 600ms at 20kHz, 300ms at 40kHz (1000 cycles/ burst)

Pause between each band: 500ms

Dead-time for push-pull driver: 5μs

Output drive: 250V AC (up to 800V peak-to-peak)

Low voltage threshold: 11.5V (switch-on voltage = 12V)

Supply Voltage: 11.5V to 16V maximum

Current drain: 220mA average at 12V driving a 3.6nF load

Peak current at transducer resonance: 3A

Quiescent current below 11.5V: 6.7mA

Our system works along the same lines as commercial systems. It uses a high-power piezoelectric transducer, which is attached inside the hull. It is driven with bursts of ultrasonic signal ranging between about 20kHz and 40kHz.

The reason for using a range of frequencies is two-fold. First, we want to drive the transducer over a range of frequencies so that various resonance modes of the hull are excited. Second, this range of frequencies is required to kill the various types of algae.

While a high-power transducer is used and we do drive it with very high voltages, the actual power used is not very great. The typical current consumption from a 12V battery is around 220mA (3A peak).

The large ultrasonic transducer is driven with high-frequency signal bursts ranging from 19.08kHz up to 41.66kHz.

Since the ultrasonic anti-fouling system should ideally run continuously, the 12V battery will need to be permanently on charge. This is no problem for boats in berths which have shore power (ie, 230V AC mains). For boats on swing moorings, a solar panel and battery charge controller will be required. We hope to describe a suitable system in a future issue.

So let's have a look at the ultrasonic anti-fouling driver. This is housed in a compact sealed plastic IP65-type case, with a transparent lid. There are two cable glands on one side of the case for the power supply cable and for the cable to the piezoelectric transducer, which is itself encapsulated in a high-pressure plumbing fitting.

The driver module is based on a PIC12F675-I/P microcontroller, two power MOSFETs and a step-up transformer. It can be powered from a 12V battery or a 12V 3A (or greater) power supply, if shore power is available.

Ultrasonic bursts

In more detail, the piezoelectric transducer is driven with bursts of high-frequency signal ranging from 19.08kHz through to 41.66kHz. This is done over 14 bands, with each band sweeping over a small frequency range.

The first band is from 19.08kHz to 20.0kHz and comprises 12 frequencies, with approximately 83Hz steps between each frequency. The other bands also have 12 frequencies, but with larger frequency steps. For the middle band at 24.75kHz to 26.31kHz, the steps are about 141Hz. For the top band, between 37.87kHz and 41.66kHz, the steps are 344Hz.

Each band overlaps the following band by a few hundred hertz. This overlap ensures that the whole range of frequencies is covered from 19.08kHz to 41.66kHz.

Each burst of signal comprises two separate frequency bands, each of 500 cycles. The burst period for the total 1000 cycles depends on the actual frequency bands that are in the burst – from 300ms to 600ms. There is a 500ms no-signal gap between each burst.

The two frequency bands for each burst are varied in a pseudo-random way so that the entire range of frequencies is covered within 16s. This sequence is repeated after about 64s.

Note that there is a concentration of signal about the resonant frequency of the transducer, between 35.21kHz and 41.66kHz.

Circuit description

Now let's have a look at the full circuit diagram for the *Ultrasonic Anti-Fouling Driver* – see Fig.1. The PIC microcontroller IC2 drives step-up transformer T1 via two MOSFETs, Q1 and Q2. In addition, the microcontroller provides a low-voltage shutdown to prevent the battery from discharging below 11.5V.

The microcontroller runs at 20MHz (as set by crystal X1) and this allows it to provide the small ultrasonic frequency shifts listed above.

Pin 6 and Pin 7 of IC2 drive MOSFETs Q1 and Q2, which in turn drive transformer T1. Since these outputs only swing from 0V to +5V, we have specified logic-level MOSFETs, type RFP30N06LE. Their 'on' resistance (between the drain (D) and source (S)) is a mere 75mΩ for a gate voltage of 3V, and it drops even lower to around 23mΩ at a gate voltage of 4.5V. Their current rating is 30A continuous.

MOSFETs Q1 and Q2 are driven alternately and in turn drive separate halves of the transformer primary winding. The centre tap of the primary is connected to the +12V supply rail.

When Q1 is switched on, current flows through its section of the primary winding for less than 50µs, depending on the frequency, after which Q1 is switched off. After 5µs, Q2 is then switched on for less than 50µs. Then, when Q2 switches off, there is another gap of about 5µs before Q1 is switched on again and so on.

The 5µs period during which both MOSFETs are off is 'dead time' and it allows one MOSFET to fully switch off before the other is switched on.

The alternate switching of the MOSFETs generates an AC square-wave in T1 primary winding and this is stepped up in the secondary winding to provide a voltage of about 250V AC, depending on the particular frequency being switched and the resonance of the piezoelectric transducer load.

MOSFETs Q1 and Q2 include overvoltage protection to clamp drain voltages which exceed 60V. This clamping is required because a high-voltage transient is generated each time the MOSFETs switch off.

Protection for the gates of the MOSFETs is provided using 5.1V Zener diodes ZD1 and ZD2. This might seem unnecessary since the MOSFETs are only driven from a 5V signal, but the high transient voltages at the drains can be coupled into the gate via capacitance. These 5.1V Zener diodes also help prevent damage to the GP0 and GP1 outputs of IC2.

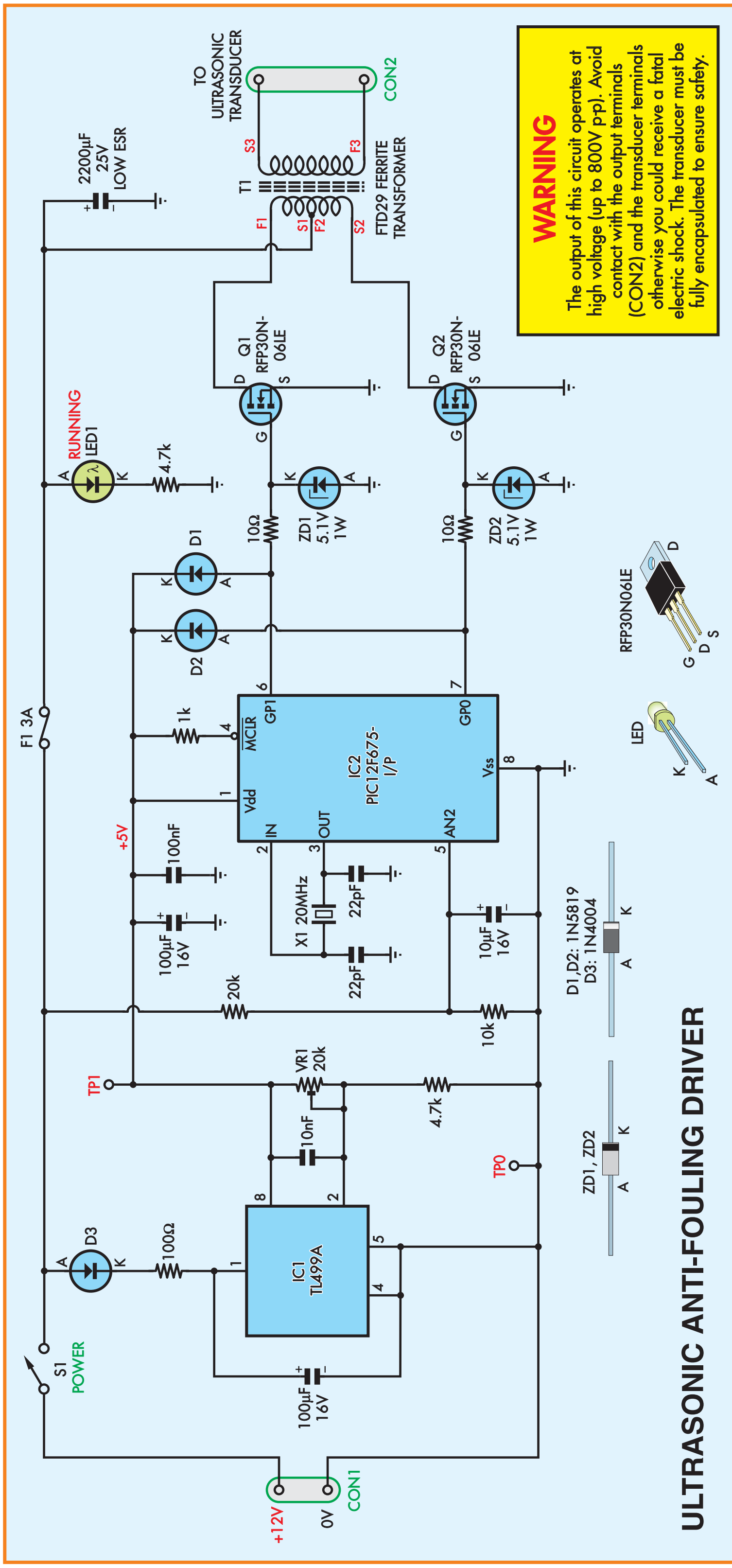
Further protection is provided for the GP0 and GP1 outputs of IC2 using Schottky diodes D1 and D2. These clamp the voltages at these pins to about +5.3V. They are in parallel with the internal protection diodes at GP0 and GP1.

Battery voltage monitoring

The incoming 12V supply is monitored via a voltage divider consisting of 10kΩ and 20kΩ resistors and the resulting voltage is filtered and monitored by IC2 at pin 5, the AN2 input. IC2 converts this voltage into a digital value and this is compared against a reference value in the software. With an 11.5V supply, the voltage at pin 5 is 3.83V and below this threshold voltage IC2 cuts off the drive for MOSFETs Q1 and Q2. This prevents over-discharge of the boat battery.

Once IC2 is in low-voltage shutdown mode, the supply voltage needs to rise to 12V before the MOSFET drive is resumed. This 0.5V hysteresis prevents the shutdown switching being on and off repetitively at the 11.5V threshold.

The 5V supply rail for IC2 is provided by a TL499A regulator, IC1. This is a low quiescent current regulator that can run in linear stepdown or switch-mode step-up modes. We are using it



ULTRASONIC ANTI-FOULING DRIVER

Fig.1: the circuit uses PIC microcontroller IC2 to drive step-up transformer T1 in push-pull fashion via MOSFETs Q1 and Q2. IC1 is a switch-mode controller IC and is used to provide the +5V supply rail for IC2, while ZD1 and ZD2 provide overvoltage protection for the gates (G) of the MOSFETs.

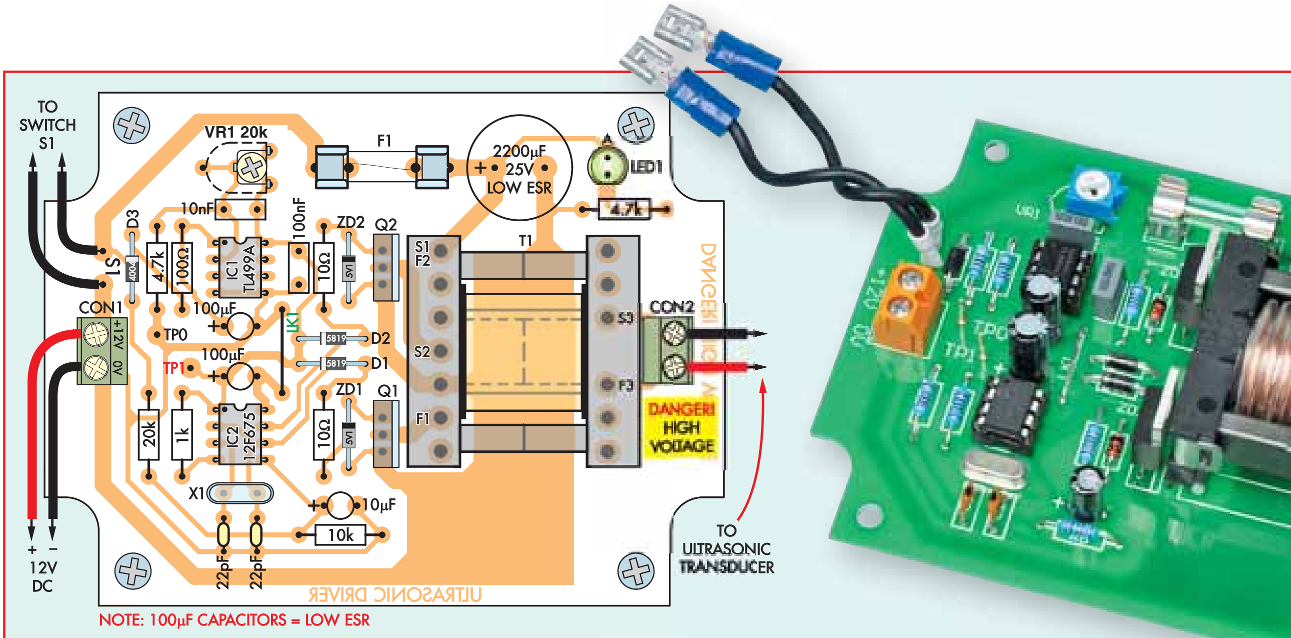


Fig.2: install the parts on the PC board as shown in this layout diagram and the photo. Be sure to use a socket for the PIC microcontroller (IC2), but do not install this IC until after the setting-up adjustment has been completed.

in linear stepdown mode. Its output voltage is trimmed to exactly 5V using trimpot VR1. This is done to set the low-voltage shutdown threshold.

The circuit includes reverse polarity protection. IC1 is protected by diode D3 and in turn protects IC2. The MOSFETs are protected via their substrate diodes and fuse F1.

If the supply is reversed, the diodes conduct via the transformer's primary until the fuse blows. Before that happens, the supply is effectively clamped at around –1V, and thereby protects the 2200µF electrolytic capacitor from excessive reverse voltage.

The fuse also prevents the PC board tracks from fusing should the transformer be wound incorrectly or if one of the MOSFETs fails as a short circuit.

Assembly details

The *Ultrasonic Driver* is constructed on a PC board measuring 104mm × 78mm. This board is available from the *EPE PCB Service*, code 866. It has corner cutouts to allow it to be mounted in an IP65 ABS box with a clear lid, measuring 115mm × 90mm × 55mm.

Begin construction by checking the PC board for breaks in the copper tracks or shorts between them. Check also that the hole sizes are correct for each component to fit neatly. The screw terminal holes and transformer pin holes are 1.25mm, while still larger holes are used for the fuse clips.

Assembly can begin by installing the resistors and PC stakes. Table 1 shows the resistor colour codes, but you should also check each resistor using a DMM. The PC stakes are installed at TP0 and TP1 and at the external wiring points for switch S1.

Follow these with the diodes, which must be oriented as shown. Note that there are three different diode types: 1N5819s (Schottky) for D1 and D2, 1N4004 for D3 and 5.1V Zener diodes for ZD1 and ZD2.

IC2 is mounted on an 8-pin IC socket, so install this socket now, taking care to orient it correctly. Leave IC2 out for the time being though. IC1 can also be socket mounted or it can be directly soldered into place. Again, ensure the orientation is correct.

Crystal X1 and the two 2-way screw terminal blocks can be installed next. Make sure the screw terminals are oriented with the opening toward the outside edge of the PC board. Q1 and Q2 must be mounted so that their tabs are 25mm above the PC board. Their metal tabs face transformer T1.

LED1 is mounted with its top 30mm above the PC board (its anode has the longer lead). The capacitors can now go in, followed by trimpot VR1. Make sure that the electrolytic capacitors are oriented correctly.

Transformer details

Fig.3 shows the transformer winding details. The primary winding

Table 1: Resistor Colour Codes

❏	No.	Value	4-Band Code (1%)	5-Band Code (1%)
❏	1	20kΩ	red black orange brown	red black black red brown
❏	1	10kΩ	brown black orange brown	brown black black red brown
❏	2	4.7kΩ	yellow violet red brown	yellow violet black brown brown
❏	1	1kΩ	brown black red brown	brown black black brown brown
❏	1	100Ω	brown black brown brown	brown black black black brown
❏	2	10Ω	brown black black brown	brown black black gold brown

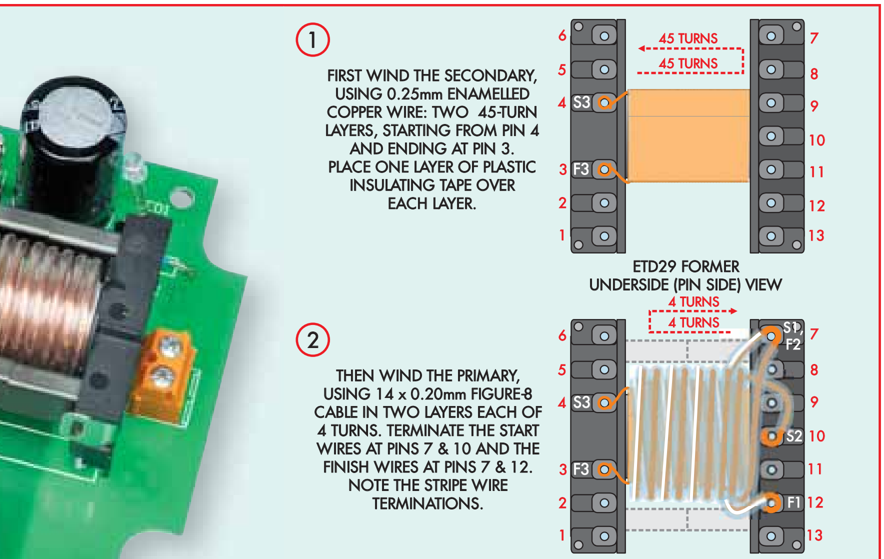


Fig.3: winding the transformer. The secondary is wound using 0.25mm enamelled copper wire, while the primary is wound using the specified figure-8 cable – see text.

uses eight turns of figure-8 14mm × 0.20mm wire, wound in two layers, to give a bifilar winding. The secondary uses 0.25mm enamelled copper wire wound in two layers of 45 turns each, with insulation tape between the two layers.

While this may seem confusing, the secondary winding is done first. To do this, first strip the enamel from one end of the 0.25mm enamelled copper wire using some fine emery paper or a hobby knife to scrape it off. Pre-tin the wire end and wrap it around pin 4 on the underside of the transformer bobbin and solder it close to the bobbin.

Now wind on 45 turns side-by-side to make the first layer. The direction of winding (whether clockwise or anticlockwise) doesn't matter. Cover this winding layer with a single layer of plastic insulation tape. Now continue winding in the same direction back across the insulation tape to complete 90 turns. Terminate the wire onto terminal 3, then cover the secondary winding in a layer of insulation tape.

The primary winding, made from the figure-8 cable, is first stripped of 10mm of insulation at one end and the two wires are soldered to the bobbin at pins 7 and 10, with the grey polarity stripe to pin 7. Now wind on four turns, making sure the wire lies flat without twists, so that the striped wire stays to the left. The four turns should fully fill the bobbin and the next four turns will be on the next layer (there's no need for insulation tape between them). Terminate the striped wire end onto pin 12 and the other wire to pin 7.

Once wound, slide the cores into the former and secure with the clips. These clips push onto the core ends and clip into lugs on the side of the bobbin.

The transformer can now be installed on the PC board. Note that its primary side has seven pins and the secondary side has six pins, so it can only go in one way. That completes the PC board assembly.

Mark out and drill the hole in the lid of the case for switch S1 – see photo on p29. When mounting the switch, make sure that it is firmly seated in the clear lid. If it tends to pop out of place, you will need to use some silicone sealant to ensure it is firmly anchored (*and waterproof*).

Software

All software program files will be available from the *EPE* website at **www.epemag.com**.

Although we do not supply pre-programmed microcontrollers, you can purchase the programmed micro featured in this project from: **parts@siliconchip.com.au**

Parts List

1 PC board, 866, available from the *EPE PCB Service*, size 104mm × 78mm
1 IP65 type ABS box with clear lid, 115mm × 90mm × 55mm (Jaycar HB6246 or equivalent)
1 50W ultrasonic transducer with 40kHz resonance (Jaycar AU5556 or equivalent)
1 ETD29 ferrite transformer (RS Components 231-8656) with 2 × 3C85 cores, a 13-pin former and 2 retaining clips (T1)
1 IP65 10A push-on/push-off switch (S1) (Jaycar SP-0758)
1 300mm length of 14 × 0.20mm figure-8 wire
1 3m length of 0.25mm enamelled copper wire
1 100mm length medium-duty hookup wire
1 3A M205 fuse
2 M205 PC fuse clips
2 2-way screw terminals with 5mm or 5.08mm pin spacing
1 8-pin IC socket
2 IP65 6.5mm cable glands
1 20MHz crystal (X1)
4 PC stakes
4 M3 × 6mm screws
2 6.4mm female spade lugs
1 20mm length 3mm-diameter heatshrink

Semiconductors
1 TL499A switch-mode controller (IC1)
1 PIC12F675-I/P programmed microcontroller (IC2)
2 RFP30N06LE MOSFETs (Q1,Q2)
2 1N4733 5.1V 1W Zener diodes (ZD1,ZD2)
2 1N5819 1A Schottky diodes (D1,D2)
1 1N4004 1A diode (D3)
1 3mm LED (LED1)

Capacitors
1 2200µF 25V low ESR elect.
2 100µF 16V low ESR elect.
1 10µF 16V electrolytic
1 100nF MKT polyester
1 10nF MKT polyester
2 22pF ceramic

Resistors (0.25W, 1%)
1 20kΩ
1 10kΩ
2 4.7kΩ
1 1kΩ
1 100Ω
2 10Ω
1 20kΩ horizontal trimpot (VR1)

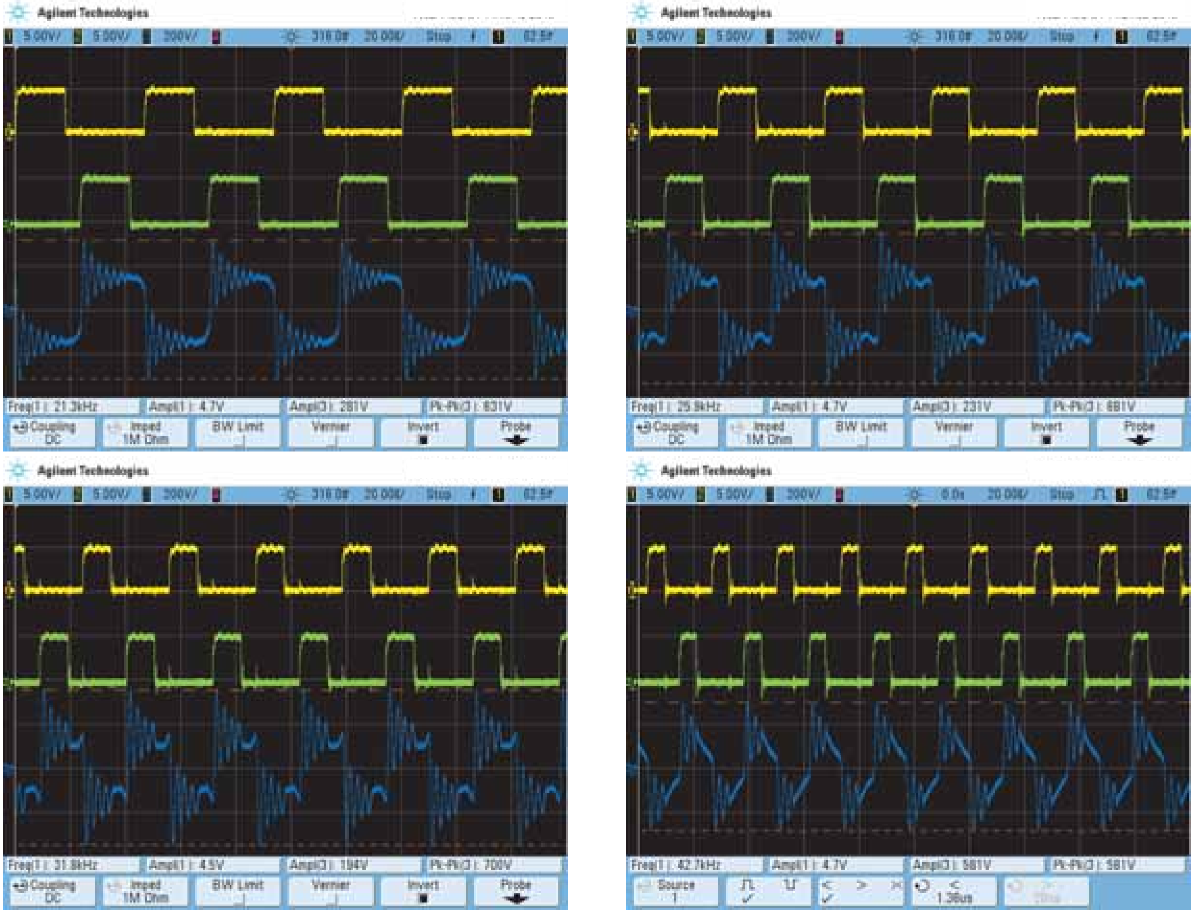
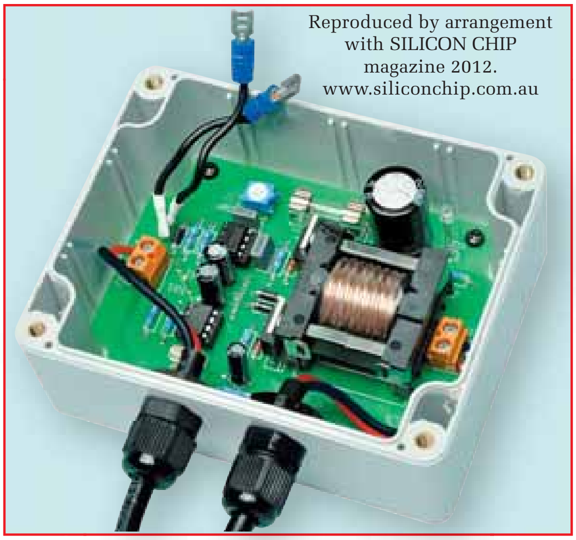


Fig.4: the yellow and the green waveforms in each of these scope grabs show the alternate gate signals for MOSFETs Q1 and Q2, while the lower (blue) trace shows the resulting high-voltage waveform in the secondary of the transformer. Four scope grabs are shown here to show the range of frequencies covered and these are varied in a pseudo-random sequence.



Driver board mounted inside the case. Do not apply power to the completed unit unless the transducer (which must be fully encapsulated) is connected – see text.

Two holes are required in one side of the box for the power lead cable gland and for the cable to the ultrasonic transducer. These cable gland holes are located 27mm up from the bottom of the case and are positioned as shown in the photos. They are both 12mm in diameter.

Adjustment

Before going further, remove fuse F1 and check that IC2 has NOT been fitted to its socket. This ensures that no high voltages appear at the output during adjustment. That done, secure the board in the case using four M3 x 6mm machine screws into the integral supports, then connect a DMM set to read DC volts between TP1 and TP0. Apply power and adjust VR1 for a reading of 5V.

Now disconnect the power and install IC2 and the fuse. Once this has been done, do not apply power again unless the transducer is connected and then only after the latter has been fully encapsulated – see warning panel.

Next month, we will describe how to encapsulate the piezoelectric transducer in a standard high-pressure 50mm male adaptor. We will also show you how to install the finished transducer assembly and driver module in the hull of a fibreglass cruiser.

Electrolytic capacitor reformer and tester

Last month, we introduced our electrolytic reformer/tester circuit. We now show how to construct, test, and use the tester to breathe (usually) new life into your collection of vintage/suspect electrolytics.

Part 2: by JIM ROWE

WITH the exception of the power supply, microswitch (S6) and, of course, the capacitor under test/reforming, virtually all of the circuitry and components used in the *Electrolytic Capacitor Reformer and Tester* are mounted on a single PC board measuring 222mm × 120mm and coded 861. This board is available from the *EPE PCB Service*.

The board is supported behind the transparent lid of the case – in fact, a modified storage organiser – which houses the instrument.

As you can see from the photos and assembly diagrams, the board is suspended from the lid of the enclosure and label (which becomes the instrument's front panel) via four 25mm long M3 tapped spacers.

The LCD display module mounts just above the centre of the board on four 12mm-long M3 tapped nylon spacers (or two such spacers if you use the Altronics LCD module).

The DC-to-DC converter's step-up transformer T1 (wound on a 26mm ferrite pot core) mounts on the board at upper left using a 25mm-long M3 nylon screw and nut, while voltage selector switch S1 also mounts directly on the board at lower left.

The only components not mounted directly on the board are power switch S2, pushbutton switches S3 to S5, the two test leads (fitted with alligator clips) and, as mentioned earlier, the microswitch. All switches are mounted on the front panel, with their rear connection lugs extended down via short lengths of tinned copper wire to make their connections to the board. All of these assembly details should be fairly clear from the diagrams and photos.

Board assembly

To fit the components on the main board we suggest you start with the fixed resistors. These are all 1% tolerance metal film components, apart from the 0.27Ω, 2.2kΩ and 8.2kΩ 5W resistors and the 2 × 1kΩ 1W resistors.

When you are fitting all of the resistors, make sure you place each value in its correct position(s), as any mix ups may have a serious effect on the meter's operation and/or accuracy. Check each resistor's value with a DMM (digital multimeter) if you want to be sure of no mistakes.

It's also a good idea to fit the 1W and 5W resistors with their bodies about 2mm above the top of the board, rather than resting on it. That's because these resistors can become quite warm during an extended 'electro reforming' test run.

It's logical to follow with the wire links, most of which are 0.4mm long, so they're easily fashioned from resistor lead offcuts. There are quite a few of these links – five are located underneath the position where the LCD module is fitted later – see Fig.3.

Next, place the eleven 1mm terminal pins in the board – two for each of the three test point locations, two for the DC input connection and three for the high voltage output (to the microswitch and capacitor). Follow these with the sockets for IC1 and IC2 (both 8-pin sockets) and IC3 (an 18-pin socket).

After these are in place you can fit 25-turn trimpot VR1 at centre left and trimpots VR2 and VR3 at upper right. Next are the small low-value capacitors, followed by the two larger 470nF/630V metallised polyester units and finally the two high voltage electrolytics, which lie on their side at the top of the board with their leads bent down by 90°. They are each held down using

WARNING: SHOCK HAZARD!

Because the voltage source in this instrument can be set to provide quite high DC voltages (up to 630V) and can also supply significant current (tens of milliamps), it does represent a potential hazard in terms of electric shock. We have taken a great deal of care to ensure that this hazard is virtually zero if the instrument is used in the correct way – ie, with the lid closed and secured – even to the extent of quickly discharging any capacitor when the lid is opened.

However, if the safety switching is bypassed, especially when the unit is set to one of the higher test voltages, it is capable of giving you a very nasty 'bite' should you become connected across the test clips or a charged high voltage capacitor. There are some situations where such a shock could potentially be lethal.

Do NOT bypass the safety features included in this design. We don't want to lose any readers to electrocution.

The completed reformer and tester built into its modified 'storage organiser' case. The circuit, including the test clips, is completely isolated when the lid is closed and any charge on the capacitor under test/reforming is bled away safely when the lid is opened. There is plenty of room inside the case for the 12V DC power supply and in this case its IEC lead, which in use emerges from a hole cut in the side of the case alongside the supply.

a nylon cable tie which goes through the hole in the PC board and around the edge. Once the high voltage electros are in place you can mount the low voltage electros, three of which go at far right and the remaining 47μF unit at lower centre just near TP2.

Don't forget to fit all of the electros with the orientation shown in the PC board overlay diagram (Fig.3), as they are all polarised.

Selector switch

Next fit the two relays, making sure that they too are oriented as shown in Fig.3. Then you can solder in voltage selector switch S1, which as you can see mounts with its indexing spigot in the '1:30' position. Before you fit the switch you should cut its spindle to a length of about 12mm and file off any burrs, so it's ready to accept its knob.

After switch S1 has been fitted to the board, remove its main nut/lockwasher/position stopwasher combination and turn the spindle by hand to make sure it's at the fully anti-clockwise limit. Then refit the position stopwasher, making sure that its stop pin goes down into the hole after the moulded '11' digits.

Next, refit the lockwasher and nut to hold it down securely, allowing you to check that the switch is now 'programmed' for the correct eleven positions – simply by clicking it around through them by hand. You'll probably need to temporarily attach the knob first to get enough grip to turn it. If all is OK, remove the knob for now.

The next step is to wind the step-up autotransformer T1. This might sound a bit daunting, but it's not. You can find step-by-step instructions in the panel titled 'Winding Transformer T1', which also explains how to fit the completed transformer to the PC board.

Final components

With the transformer wound and fitted to the board, you'll be ready to install diodes D1 to D6. These are all polarised, so make sure you position each one correctly, as shown in Fig.3. Also ensure that D1 to D3 are the three 1N4148 diodes, D4 is the UF4007 and the two 1N4004 diodes for D5 and D6. When fitting the two Zener diodes ZD1 and ZD2, note that they are NOT the same voltage – they too are polarised.

After the diodes, install transistors Q1, Q2, Q4 and Q5, which are all TO-92 devices. Make sure that you fit the two BC337 (*NPN*) devices as Q1 and Q4, with the BC327 (*PNP*) devices as Q2 and Q5. You can follow these with voltage reference IC4, which is also in a TO-92 package. If in any doubt, use a magnifying glass to confirm the device's type numbers.

Next come regulator REG1 and Q3, which are both in TO-220 packages. In this project, they each lie flat on the top of the board with a 19mm-square (6073B type) heatsink underneath, and with their leads bent down by 90° at a point about 6mm away from the body. Each device is then held in position on the board using a 6mm-long M3 machine screw and nut. These should be tightened before the leads are soldered to the pads underneath to prevent stress on the pads.

Next, fit LED1 to the board. It is located just to the right of the socket for IC1, with its cathode 'flat' side towards rotary switch S1. Note that it is fitted vertically, with its leads left almost at their full length – so that the bottom of the LED's body is about 22mm above the top of the board. This should mean that the top of the LED's body will just protrude from the matching hole in the case lid, after final assembly.

LCD mounting

The final component to be mounted directly on the board is the connector for whichever LCD module you are going to use. In the case of the Jaycar QP-5516 module, this will be a 14-way (7x2) length of DIL (dual inline) socket strip, fitted vertically at the left-hand end of the module position. Whereas, if you are using the Altronics Z-7013 module, you will need to fit a 16-way length of SIL socket strip horizontally, along the lower long side.

Once this connector has been fitted and its pins soldered to the pads underneath, you'll be almost ready to mount the LCD module itself.

All that will remain before this can be done is to attach to the board either four or two 12mm-long M3 tapped *nylon* spacers, in the module mounting positions. This will mean two at each end in the case of the QP-5516 module,

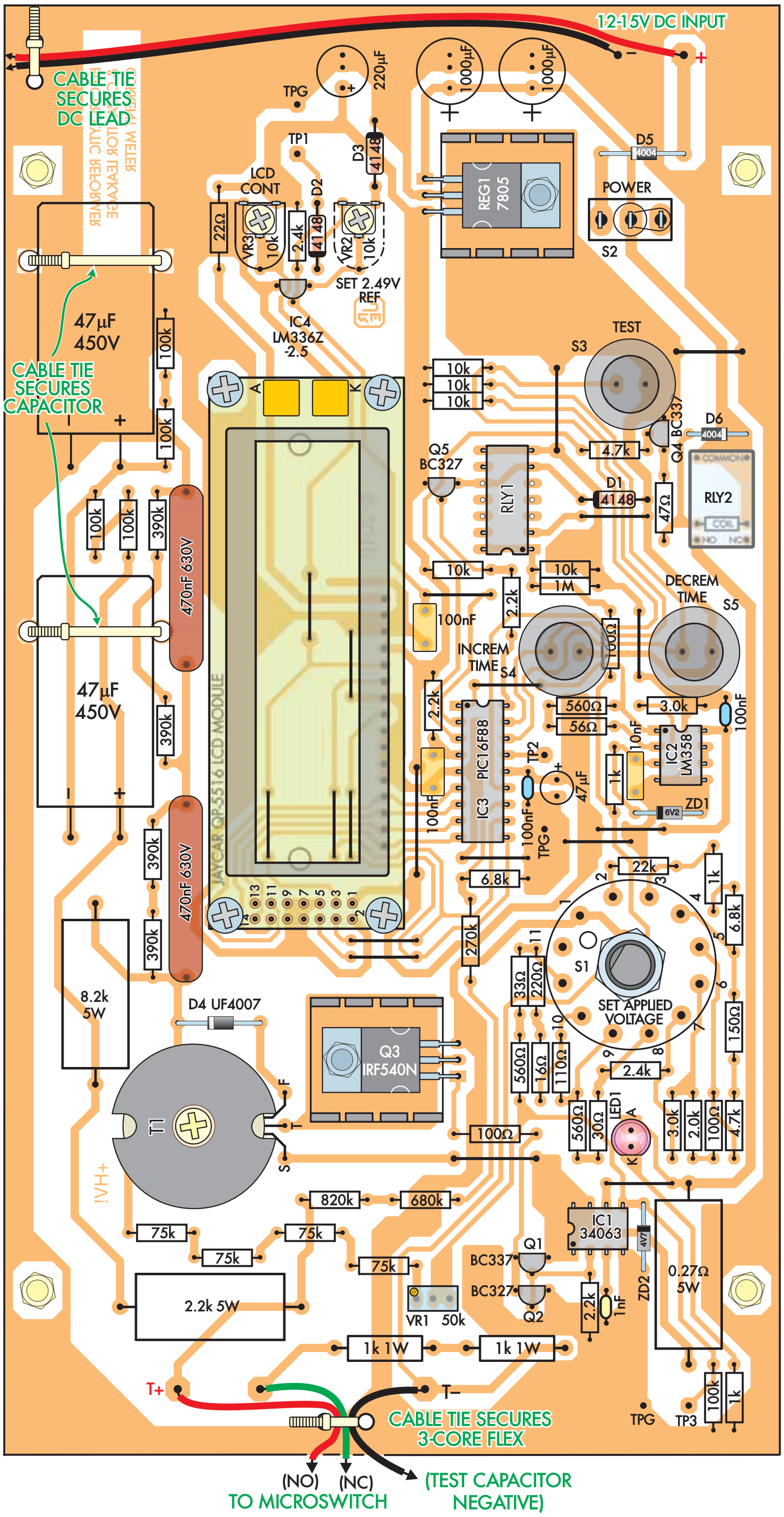


Fig.3: Apart from the 12V plugpack, interlock microswitch and test leads/clips, everything mounts on or is attached to the one large PC board, as shown here. The cable ties reduce the flexing on the soldered joints as the case is opened.

or only one at each end in the case of the Z-7013 module.

In each case, attach the spacers using a 6mm M3 screw passing up through the board from underneath – but in the case of three of the four screws for the QP-5516 module, you'll need to fit an M3 nylon flat washer under each screw head as these screws are unavoidably close to copper tracks under the board.

Next 'plug' a 7×2 length of DIL pin strip into the socket strip you have just fitted to the board for the QP-5516 module, or a 16-way length of SIL pin strip into the socket strip for the Z-7015 module. Make sure the longer ends of the pin strip pins are mating with the socket contacts, leaving the shorter ends uppermost to mate with the holes in the module.

Now remove the LCD module from its protective bag, taking care to hold it between the two ends so you don't touch the board copper. Lower it carefully onto the main board so the holes along its left-hand end (QP-5516), or along its lower front edge (Z-7015), mate with the pins of the pin strip, allowing the module to rest on the tops of the 12mm-long nylon spacers.

Then you can fit either one or two more 6mm M3 screws to each end of the module, passing down through the slots in the module and mating with the spacers. When the screws are tightened (but not **over** tightened) the module should be securely mounted in position.

The final step is to use a fine-tipped soldering iron to carefully solder each of the 14 or 16 pins of the pin strip to the pads on the LCD module, to complete its interconnections.

After this is done you can plug the three main ICs into their respective sockets, making sure to orientate them all as shown in Fig.3.

Your PC board assembly should now be just about complete. Before finishing it off (ie, putting it in the case), we will run a few checks on it to make sure everything is OK.

Checkout and setup

NOTE: the following checks MUST be done with selector switch S1 on a LOW voltage setting (say 35V or less). NEVER, never apply power to the unit with S1 on a higher voltage setting without the PC board fitted to the case and the safety interlock in place.

Winding transformer T1

Many constructors are put off projects which involve winding a transformer, but in most cases, it's not too difficult a job and requires just a little care and attention to detail.

In the case of the *Electrolytic Capacitor Reformer and Tester*, step-up autotransformer T1 has only 90 turns of wire in all, with an initial primary winding of 10 turns of 0.8mm diameter enamelled copper wire followed by four 20-turn layers of 0.25mm diameter enamelled copper wire to form the secondary.

And as you can see from the coil assembly diagram (Fig.4, below), all five layers are wound on a small nylon bobbin which fits inside a standard ferrite pot core (bobbins are sold to match the cores).

Coil winding

Here's the procedure: first you wind on the primary using 10 turns of 0.8mm diameter enamelled copper wire, which you'll find will neatly take up the width of the bobbin providing you wind them closely and evenly. Cover this first layer with a 9mm-wide strip of plastic insulating tape or 'gaffer' tape, to hold it down.

Now twist the start of the 0.25mm wire around the 'finish' end of the primary winding and proceed to wind on the first layer of the secondary – winding in the same direction as you wound the primary, of course.

In this case, you should find that 20 turns will neatly take up the width of the bobbin, providing you again wind them closely and evenly.

After winding this first layer of the secondary, cover it with another layer of insulating tape. Then wind on another layer, again of 20 turns and cover it with a layer of insulating tape as before.

Exactly the same procedure is then followed to wind on the third and fourth layers of the secondary.

Each of these extra layers should be covered with another 9mm-wide strip of plastic insulating tape just as you did with the first layer, so that when all five layers have been wound and covered, everything will be nicely held in place.

The 'finish' end of the wire can then be brought out of the bobbin via one of the slots (on the same side as the primary start and primary finish/secondary start leads) and your wound transformer bobbin should be ready to fit inside the two halves of the ferrite pot core.

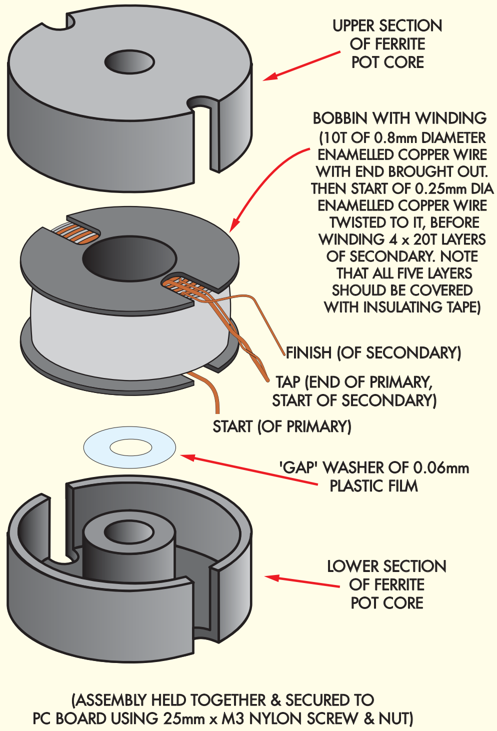


Fig.4. Ferrite pot core assembly

Just before you fit the bobbin inside the bottom half of the pot core, though, there's a small plastic washer to prepare. This is to provide a thin magnetic 'gap' in the pot core when it's assembled, to prevent the pot core from saturating when it's operating.

The washer is very easy to cut from a piece of the thin clear plastic that's used for packaging electronic components, like resistors and capacitors. This plastic is very close to 0.06mm thick, which is just what we need here.

So the idea is to punch a 3mm to 4mm diameter hole in a piece of this plastic using a leather punch, and then use a small pair of scissors to cut around the hole in a circle, with a diameter of 10mm. Your 'gap' washer will then be ready to place inside the lower half of the pot core, over the centre hole.

Once the gap washer is in position, you can lower the wound bobbin into the pot core around it and then fit the top half of the pot core. Your autotransformer should now be ready for mounting on the PC board.

Mounting on the PCB

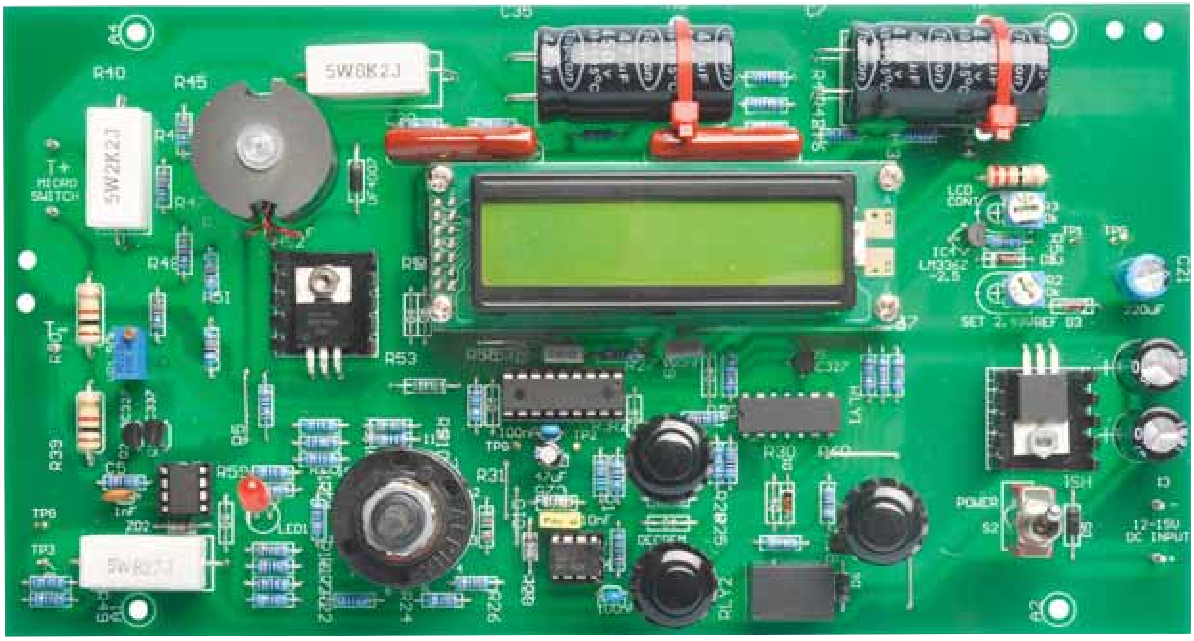
To begin this step, place a nylon flat washer on the 25mm-long M3 nylon screw that will be used to hold it down on the board. Then pass the screw down through the centre hole in the pot core halves, holding them (and the bobbin and gap washer inside) together with your fingers.

Then lower the complete assembly down on the upper left of the board with the 'leads' towards the bottom, using the bottom end of the centre nylon screw to locate it in the correct position.

When you are aware that the end of the screw has passed through the hole in the PC board, keep holding it all together but up-end everything so you can apply the second M3 nylon flat washer and M3 nut to the end of the screw, tightening the nut so that the pot core is not only held together but also secured to the top of the PC board.

Once this has been done, all that remains as far as the transformer is concerned is to cut the primary start, 'tap' (primary finish/secondary start) and secondary finish leads to a suitable length, scrape the enamel off their ends so they can be solder 'tinned', and then pass the ends down through their matching holes in the board so they can be soldered to the appropriate pads.

Don't forget to scrape, tin and solder BOTH wires which form the 'tap' lead – if this isn't done, the transformer won't produce any output.



The finished PC board, ready for mounting in the case. While pushbutton switches S3, S4 and S5 are shown in position here for the photograph, they are normally not soldered in until the board is mounted on the front panel – they have to pass through the panel from above and are connected to the PC board via lengths of tinned copper wire.

If you connect the 12V DC plugpack to the mains and then switch on the power using S2, a reassuring glow should appear from the LCD display window – from the LCD module's backlighting. You may also be able to see the meter's initial greeting 'screen'. If not, you'll need to use a small screwdriver to adjust contrast trimpot VR3 until you get a clear and easily visible display. (VR3 is adjusted through the upper small hole just to the right of the LCD window.)

Test voltage

After a few seconds, the display should change to the Meter's measurement direction 'screen', where it tells you to set the appropriate test voltage (using S1) and also the test time period (using S4 and/or S5), before pressing the Start/Stop Voltage Application button (S3) to begin the test.

Note that if you make no adjustments to the test time period using S4 or S5, the default time period will be 10 seconds.

If you just set the test voltage and press S3 at this stage, without any capacitor connected to the alligator clips (make sure the alligator clips cannot short), LED1 should begin glowing to indicate that the test voltage is being presented to the test terminals, and the LCD display should change to read:

Vtest=ON 0m09s
Cap Lkg= 0.00mA

where the time displayed on the right end of the upper line will be decrementing to show the ON time remaining. Then, when the remaining time falls to zero, you'll hear a soft 'click' and LED1 will go dark to indicate that the test voltage has been removed. At the same time, the top line of the display will change to read:

Vtest=OFF 0m 0s

while the lower line will remain unchanged.

Assuming all has gone well at this point, your unit is probably working correctly. However, if you want to set its calibration to ensure maximum accuracy of the readings, try connecting your DMM between the terminal pins TP1 and TPG (at upper right on the board, accessible via the gap between the board and front panel). You should get a reading close to 2.5V, and assuming this is the case, try adjusting trimpot VR2 with a small screwdriver until you get a reading as close as possible to 2.490V.

Now set your DMM to a range where it can read a voltage of 63V accurately and connect its probes between the meter's test terminals. Then turn S1 to the '63V' position and press S3 to turn on the test voltage source. The DMM reading should quickly rise to read very close to 63.0 volts and if so, there's no need to go further.

If the reading is not within the range of 62.5V to 63.5V, you'll need to bring it inside this range (and ideally to 63.0V) using a small screwdriver or insulated alignment tool passed down through the hole in the front panel midway between the test terminals, to adjust the setting of VR1. Once you set the test voltage on the 63V range in this way, all of the other voltage settings will be correct as well.

Note that if you haven't set the meter's timer to increase the testing time period from its default 10 seconds, the timer will turn off the test voltage after this time. So, if you want to take your time to adjust the voltage to 63V using VR1, you might want to crank up the time period using S4, to keep the test voltage present for as long as you need.

Once the 2.49V reference voltage and the 63V test voltage have been set in this way, your *Electrolytic Capacitor Reformer/Tester* has been set up correctly and will be ready to be fitted into the case.

Preparing the 'case'

As mentioned earlier, the case we have used is a little unusual. It's sold as a 'storage organiser' and is made by Trojan. Ours came from Bunnings Hardware (**www.Bunnings.co.au**), and is listed as the Trojan TJW0510 38cm type. You could try checking out your local B&Q or Wickes for something similar – it must be plastic/nylon though. It has a transparent hinged lid and in the 'body' it has three rows of fixed dividers plus quite a number of movable dividers which fit into slots moulded into the fixed dividers.

First determine where your PC board will lie inside the case. Use an enlarged photocopy of the front panel (see Fig.7) or a same-size copy of the PC board layout and use it on the outside of the case as a template for drilling.

The left-to-right position is fairly unimportant (just make sure you leave enough room for the leakage current guide if you use the PC board layout diagram). However, you need to make sure that the PC board lies exactly in the space between the vertical dividers so that when the lid is closed, it fits!

There are four holes to be drilled to mount the PC board and nine for controls/indicators. You don't need to cut a slot for the LCD readout because the lid is transparent enough to read through it. (Yeah, we know, our photos show a cutout – we did that before we realised it was transparent enough, D'oh!) You will, however, need a cutout in the front panel label.

We modified the case to accommodate the PC board by removing a 30mm deep by 215mm long section from one of the fixed dividers, then cut notches along the moulded slots about 10mm wide and about 25mm down from the top. The photo of our modified case gives a better idea.

The PC board sits down in the removed divider section and along the slot notches each side. 25mm threaded standoffs then mount the PC board to the underside of the lid, on to which we had previously glued the front panel and drilled the required holes.

You'll also need to mount the microswitch so that it is actuated when the lid is closed. The microswitch has two mounting holes through the body which make this fairly simple. It doesn't have to be horizontal when mounted, in fact a little bit of an angle makes the action on the actuator arm more certain.

Holes also need to be drilled through the divider walls to allow the HV wires (from PC board to microswitch/negative capacitor terminal) to pass through, along with the wires from the plugpack to the PC board.

Power supply

While we have built the prototype with a switch-mode 12V, 2A plugpack, that's not the only option. The supply can be virtually any 12V to 15V DC type with a minimum of about 1.5A output – just so long as it fits inside the case.

If you use a plugpack, it obviously needs to be outside the unit when in operation. Therefore, a small slot can be cut in the outside vertical wall of the case, just deep enough to allow the figure-8 cable to pass through when the lid is closed and locked.

An alternative is to use a switch-mode adaptor supply – one we had on hand was a 12V, 4A type. At 60mm wide, this particular supply fits nicely into the case, as our photo shows.

Yet another, often much cheaper alternative, is to use what is commonly sold as a 'hard disk drive' supply – they're usually about the same size as the above model (or a little less), and have a 12V, 2A DC ouput (along with a 5V 2A ouput which can be ignored).

The latter supply is often sold with, or is available for, external hard disk drives and we've seen them advertised for less than £5 each.

Both of these supplies generally have an IEC socket, so a standard IEC power cable can be used. To do this, a 30mm hole could be cut in the case side to allow the supply's IEC plug to fit through, which would then allow the supply to remain inside the case when in use.

There's even room to store an IEC cable inside the case in the area you would normally connect the capacitor under test/reforming.

We used the front third of the case for the capacitor under re-forming or test, and storage for the supply. One of the supplied orange dividers makes neat separate compartments for both the capacitor and the supply.

Fitting the front panel

Before proceeding to final assembly, tinned copper extension wires need to be soldered to the three pushbutton switches (S3 to S5) which will go through the front panel from above and soldered to the underside of the PC board when it is in position.

A tip here is to make all of the S3 to S5 extension wires slightly different lengths and longer than you'd think necessary (say from 30mm to 50mm) so that when one goes in, it doesn't pop out doing the next one.

Unfortunately, the front panel is longer than a page, so we haven't been able to provide a same-size artwork as normal. You will need access to an enlarging colour photocopier, and you will need to be able to print A3 paper.

To provide a little more protection and rigidity, we laminated ours (again, an A3 laminator is required), cut out all the holes (including the LCD hole) then glue it, face-side up, inside the lid of the case using spray adhesive.

Hopefully, all the holes you previously drilled in the panel will line up with those you drilled earlier.

Allow the glue to dry and you should now be ready for the only slightly fiddly part of the assembly operation: attaching the PC board assembly to the rear of the lid/front panel.

This is only fiddly because you have to line up all of the extension wires from switches S2 to S5 with their matching holes in the PC board, while you bring the lid and board together and at the same time line up the body of LED1 along with switches S1 and S2 with their matching holes in the front panel.

Just take your time and the lid will soon be resting on the tops of the board mounting spacers. Make sure LED1 is poking through its hole, then you can secure the two together using the four remaining 6mm-long M3 machine screws, with washers underneath the heads to protect the relatively soft plastic of the case lid.

Now it's a matter of soldering each of the switch extension wires to their board pads. Once they are all soldered you can clip off the excess wires with sidecutters.

Place the power switch washer and nut on the thread and tighten (adjust the underside nut up or down as necessary so you don't bow the plastic) and finally make sure the LED is poking through its front panel hole (Fig.5).

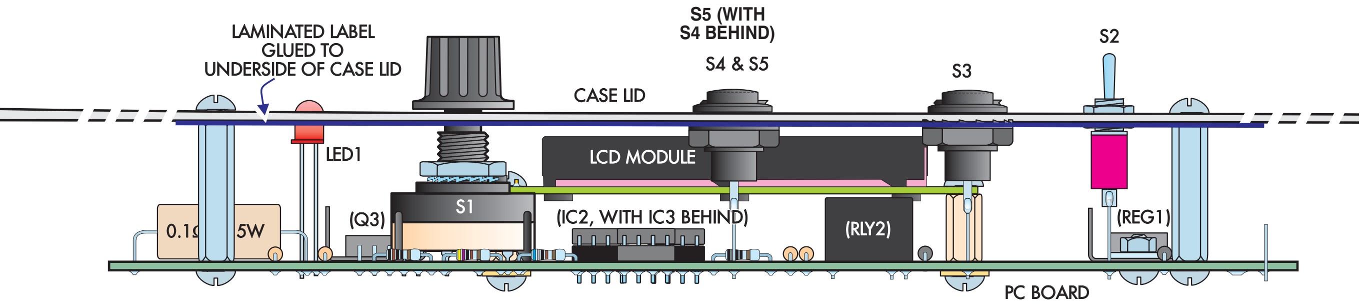


Fig.5: the PC board 'hangs' from the case lid, which becomes the front panel. The label is on the inside of the lid.

Final wiring

Power wiring (from the 12V power supply/plugpack) and high voltage wiring (to the microswitch and capacitor negative) can be attached to the PC stakes, even with the board in position. It's a bit fiddly and you have to be careful not to damage the plastic lid, but the stakes are close enough to the outer edges of the PC board to make this possible.

To protect the soldered joints, as much as possible, as the lid is opened and closed, we secured both the power supply and output cables to the PC board using small cable ties (Fig.3).

Remember to run the various wires through the holes you have drilled in the divider walls before soldering to the PC board. The power supply connections are straightforward (remember their polarity), but the high voltage wiring is just a bit more difficult. Note our comments earlier about the type of cable used for the high voltage cable: it must be rated at 250V or higher.

- *The wire from the HV+ terminal goes to the microswitch 'NO' terminal.*
- *The wire which connects to the 2 × 1kΩ 1W bleed resistors on the PC board goes to the microswitch 'NC' terminal.*
- *The wire from the microswitch 'COM' terminal goes direct to the capacitor positive (red) alligator clip.*
- *The wire from the T- terminal goes direct to the capacitor negative (black) alligator clip.*

By the way, if you find this description a bit confusing, refer to the diagrams of Fig.3 and Fig.5, and also the inside photos shown last month. These will hopefully make everything clear.

Using it

The new *Electrolytic Capacitor Reformer* is very easy to use, because all that you have to do is connect the capacitor you want to test between the alligator clips (with the correct polarity in the case of solid tantalums and electrolytics), *close* the lid, set selector switch S1 for the correct test voltage and then turn on the power using S2 (assuming you have already plugged in your plugpack supply).

When the initial greeting message on the LCD changes into the 'Set Volts and Test Time, Press Strt' message, press S4 and/or S5 to set the time period to whatever you need. Then it's simply a matter of pressing the Start/Stop Voltage Application button (S3) to start the test.

What you'll see first off may be a reading of the capacitor's charging current, which can be almost 20mA at first (with high value caps), but should then drop back as charging continues.

How quickly it drops back will depend on the capacitor's value. With capacitors below about 4.7µF, the charging may be so fast that the first reading you see may be less than 100µA, with the meter having immediately downranged.

If the capacitor you're testing is of the type having a 'no leakage' dielectric (such as metallised polyester, glass, ceramic or polystyrene), the current should quickly drop down to less than a microamp and then right down to zero. That's if the capacitor is in good condition, of course.

On the other hand if the capacitor is one with a tantalum or aluminium oxide dielectric with inevitable leakage, the current reading will drop more slowly as the test proceeds.

In fact, it may take up to a minute to stabilise at a reasonably steady value in the case of a solid tantalum capacitor, and as long as three minutes in the case of a 'good' aluminium electrolytic. (That's because these capacitors generally take a few minutes to 'reform'.)

As you can see from the guide table attached to the front panel, the leakage currents for tantalum and aluminium electrolytics also never drop down to zero, but instead fall to a level of somewhere between about 1µA and 9200µA (ie, 9.2mA), depending on both their capacitance value and their rated working voltage.

So, with these capacitors, you will need to set the meter's testing time period to at least three minutes to see if the leakage current reading drops down to the 'acceptable' level (as shown in the front panel table) and preferably even lower.

If this happens, the capacitor can be judged 'OK', but if the current never drops to anywhere near this level, then this indicates that it is in need of either reforming or replacement.

Low leakage (LL) electrolytics

The current levels shown in the table are basically those for standard electrolytics, rather than for those rated as low leakage.

So, when you're testing one which is rated as low leakage, you'll need to make sure that its leakage current drops well below the maximum values shown in the guide table. Ideally, it should drop down to no more than about 25% of these current values.

Another tip: when you're testing non-polarised (NP) or 'bipolar' electrolytics, these should be tested twice – once with them connected to the alligator clips one way around and then again with them connected with the opposite polarity.

That's because these capacitors are essentially two polarised capacitors internally connected in series back-to-back. If one of the dielectric layers is leaky, but the other is OK, this will only show up in one of the two tests.

Reforming old electros

While reading the preceding paragraphs about testing capacitors, you've perhaps

All you need to know about... electrolytics!

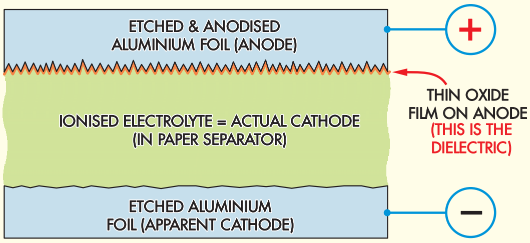


Fig.6. Typical electrolytic capacitor 'sandwich'

Most readers will be aware that all capacitors consist of two electrodes separated by an insulating dielectric.

It's the dielectric which allows the capacitor to store energy (ie, a 'charge') in an electric field between the two electrodes. The capacitance is directly proportional to the surface area of the electrodes on either side of the dielectric, and inversely proportional to the thickness of the dielectric itself. To achieve a high capacitance, the electrode area must be as large as possible, while the dielectric must be as thin as possible.

There's also another factor which determines the capacitance: the dielectric constant 'k' of the dielectric material. The capacitance is again directly proportional to this property, so to achieve a high capacitance you need to use a dielectric material with as high a k value as possible. Examples are polyester/Mylar with a k of 3.0 and mica with a k value of 6.0.

Electrolytic capacitors were developed about 90 years ago in an effort to produce high value capacitors which were at the same time much more compact than other types. Over the years they have been greatly improved, but they are still not quite as reliable and they don't have the very low leakage of other capacitors such as mica, ceramic or polyester.

As you can see from the diagram of Fig.6 (above), both electrodes in an electrolytic capacitor are made from thin aluminium foil and between them is sandwiched a sheet of paper soaked in a conducting liquid or 'electrolyte' (often sodium borate in aqueous solution, with additives to retard evaporation).

So, superficially, it would seem that we have a pair of conducting electrodes separated not by an insulating dielectric but by a sheet of paper soaked in conductive electrolyte.

But before the capacitor is assembled, the aluminium foil, which is to become the anode (positive electrode), has its surface etched in a caustic soda solution to greatly increase its surface area. This process covers the surface with an array of microscopic pits, which can have a total effective surface area of up to 60 times greater than the original unetched area for high voltage electrolytics and even higher for low voltage electros.

The etched aluminium foil is then subjected to an anodising process, whereby a very thin aluminium oxide layer covers the surfaces of all of the microscopic pits. This aluminium oxide is not only an insulating dielectric, but it also has a relatively high k value of 8.5. So electrolytics have large capacitance because of these three factors, the very high surface area of the anode, the very thin aluminium oxide dielectric and the relatively high dielectric constant of around 8.5.

The anodising process was originally referred to as 'forming', as in forming the oxide layer.

The capacitor is wound with the etched/anodised foil, a paper separator and the non-anodised aluminium foil, which becomes the negative electrode. The capacitor windings are usually then immersed in a bath of electrolyte and connected to a power supply to 're-form' the anodised layer on the positive foil, which is inevitably damaged during the winding process.

After that, the windings have their terminations connected to an aluminium can in the case of the negative electrode and to the positive terminal for the anode. The can is sealed with a rubber bung, and then it is reconnected to a power supply for a final re-form and leakage current test.

It should be noted that the electrolyte layer is critical to the performance of the capacitor. Because it is a liquid, it can fill the etched pits in the oxide layer. This means that the actual cathode is in intimate contact with the dielectric layer, minimising dielectric thickness and therefore maximising capacitance.

New electrolytic capacitors typically have a shelf life of many years, but the older they get, the higher their leakage current becomes as the oxide layer on the aluminium anode gradually deteriorates, due to the lack of a polarising DC voltage. In most cases, though, such capacitors can be rejuvenated by a re-forming process, whereby they are connected to a DC supply via a suitable current-limiting resistor.

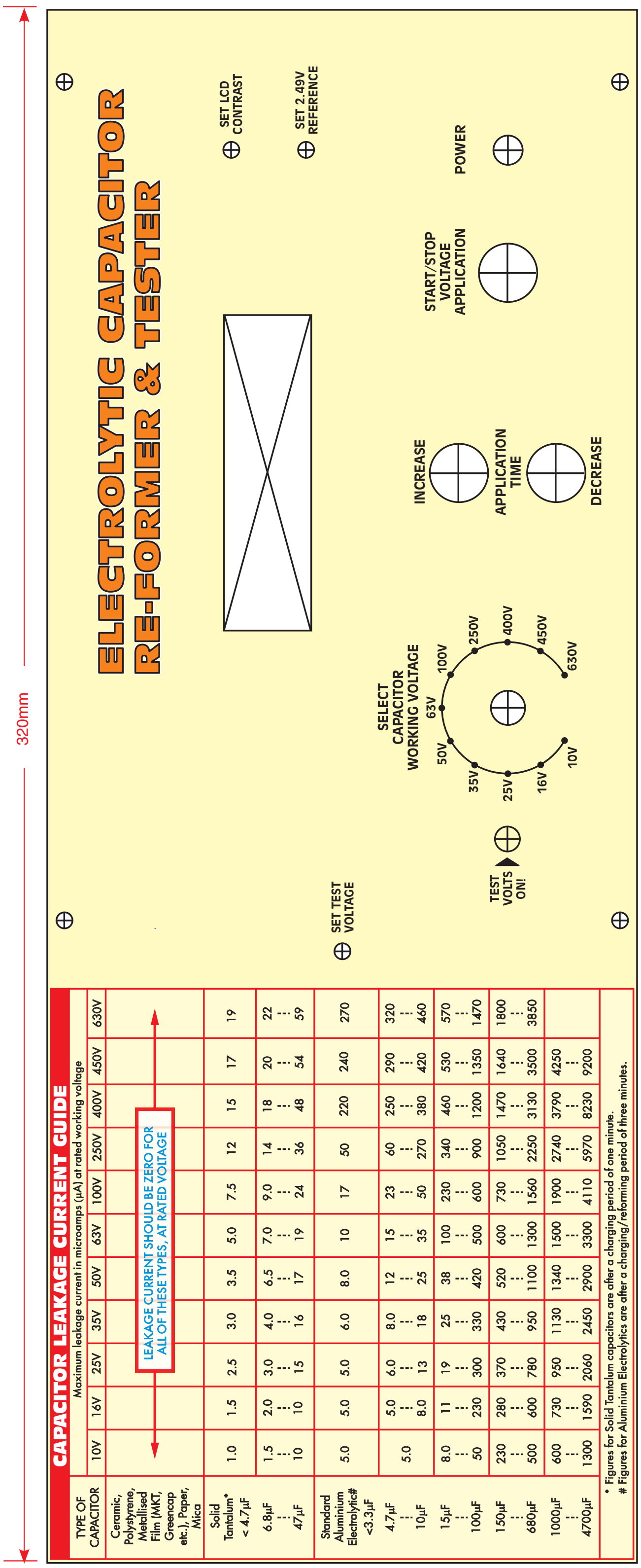
Initially, when the DC voltage is applied, the leakage current will be quite high, but it should come down within a minute or so to a value which is less than the capacitor's specified leakage current at the rated voltage. This project makes that process easy and safe for electrolytic capacitors with a wide range of voltage ratings, in addition to measuring the capacitor's leakage current.

So that's what is inside an electrolytic capacitor and that is why it is able to provide a very high capacitance in a surprisingly small package. The main drawback of electrolytics is that they always exhibit at least a small leakage current – as shown in the front panel table. So they are really only suitable for use in circuits where this small leakage current does not upset circuit operation. Luckily, this still gives them a great many applications.

been wondering about the *Reformer's* main function: reforming electrolytics that may have high leakage currents due to a long period of inactivity.

How do you use it for this function? In exactly the same way as you use it for testing capacitors, except that for reforming you set the timer for a much longer testing time period.

The idea here is that you still set S1 for the capacitor's rated voltage, but simply crank up the testing time period using S4 until it's set for either 30 or 60 minutes. Then connect the capacitor to the alligator clips (making sure of the polarity), and finally press the Start/Stop Voltage Application button (S3) to start the test/reforming operation.



TYPE OF CAPACITOR	10V	16V	25V	35V	50V	63V	100V	250V	400V	450V	630V
Ceramic, Polystyrene, Metallised Film (MKT, Greencap etc.), Paper, Mica	LEAKAGE CURRENT SHOULD BE ZERO FOR ALL OF THESE TYPES, AT RATED VOLTAGE										
Solid Tantalum* < 4.7µF	1.0	1.5	2.5	3.0	3.5	5.0	7.5	12	15	17	19
6.8µF --- 47µF	1.5 --- 10	2.0 --- 10	3.0 --- 15	4.0 --- 16	6.5 --- 17	7.0 --- 19	9.0 --- 24	14 --- 36	18 --- 48	20 --- 54	22 --- 59
Standard Aluminium Electrolytic# <3.3µF	5.0	5.0	5.0	6.0	8.0	10	17	50	220	240	270
4.7µF --- 10µF	5.0	5.0 --- 8.0	6.0 --- 13	8.0 --- 18	12 --- 25	15 --- 35	23 --- 50	60 --- 270	250 --- 380	290 --- 420	320 --- 460
15µF --- 100µF	8.0 --- 50	11 --- 230	19 --- 300	25 --- 330	38 --- 420	100 --- 500	230 --- 600	340 --- 900	460 --- 1200	530 --- 1350	570 --- 1470
150µF --- 680µF	230 --- 500	280 --- 600	370 --- 780	430 --- 950	520 --- 1100	600 --- 1300	730 --- 1560	1050 --- 2250	1470 --- 3130	1640 --- 3500	1800 --- 3850
1000µF --- 4700µF	600 --- 1300	730 --- 1590	950 --- 2060	1130 --- 2450	1340 --- 2900	1500 --- 3300	1900 --- 4110	2740 --- 5970	3790 --- 8230	4250 --- 9200	

* Figures for Solid Tantalum capacitors are after a charging period of one minute.
\# Figures for Aluminium Electrolytics are after a charging/reforming period of three minutes.

Fig.7: the front panel, which incorporates the leakage table, is too big to fit on the page, so is reproduced at exactly 75%. If you photocopy this at 133% (which in this case you can do without infringing copyright) it will come out right size. Obviously, you'll need a copier that can handle A3 paper.

Because the metering part of the instrument will continue to make measurements during the reforming period, this allows you to keep track of the leakage current as it slowly falls from its initial high figure (which may well be up in the region of 20mA). This is due to the oxide dielectric inside the electro slowly regrowing (reforming) as a result of the current passing through it.

Needless to say, if the current readings don't fall, even slowly, the electro concerned is beyond being reformed and should be scrapped.

On the other hand, if the current readings do fall significantly, but still don't come down to an acceptable level, this indicates that the electro will probably benefit from another reforming operation.

There's no problem about giving a capacitor repeated reforming operations, provided that it doesn't get overheated. In fact, significant heating is really a sign that the electro is beyond reforming and is not worth any further rescue efforts.

So this is the basic procedure, when dealing with electrolytics:

1. First give it a standard three-minute test run at rated voltage and see if the leakage current tapers down to an acceptable level during this time. If it does, the capacitor is OK.
2. If the current doesn't taper down significantly and/or the capacitor becomes overheated, it is beyond help and should be discarded.
3. If the current does taper down significantly but doesn't reach an acceptably low level, it can be regarded as a candidate for reforming. Give it a test/reforming run of 30 or 60 minutes.
4. At the end of the reforming run, test it again with a standard three-minute test period. If the leakage current is now in the acceptable range (according to the guide on the front panel), the capacitor has successfully reformed and is now OK. But if it hasn't quite finished reforming, it would be worth giving it another 30 or 60-minute session to see if this will 'do the trick'. *EPE*

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Note: power supply and case

In the parts list published last month, no mention was made of the mains power adaptor. As discussed in this month's text, you'll need a 12V to 15V DC supply at a minimum of about 1.5A. A more robust supply (ie, higher current output) won't hurt, but it does need to be able to fit into the case!

Also, six (not two) small cable ties are needed, the extras to secure the cables from the PC board to the microswitch/test leads and 11, not 10 PC pins are required.

We rather like the case chosen for this project, but you could choose an alternative – the main point is that it should be plastic/nylon and you ***must*** still include the microswitch interlock safety aspect of the design.

Jump Start

By Mike and Richard Tooley

Design and build circuit projects dedicated to newcomers, or those following courses taught in schools and colleges.

WELCOME to *Jump Start* – our new series of seasonal 'design and build' projects for newcomers. *Jump Start* is designed to provide you with a practical introduction to the design and realisation of a variety of simple, but useful, electronic circuits. The series will have a seasonal flavour, and is based on simple, easy-build projects that will appeal to newcomers to electronics, as well as those following formal courses taught in schools and colleges.

Each part uses the popular and powerful 'Circuit Wizard' software package as a design, simulation and printed circuit board layout tool. For a full introduction to Circuit Wizard, readers should look at our previous *Teach-In series*, which is now available in book form from Wimborne Publishing (see *Direct Book Service* pages 75-77 in this issue).

Each of our Jump Start *circuits include the following features:*

- ***Under the hood*** – provides a little gentle theory to support the general principle/theory behind the circuit involved
- ***Design notes*** – has a brief explanation of the circuit, how it works and reasons for the choice of components
- ***Circuit Wizard*** – used for circuit diagrams and other artwork. To maximise compatibility, we have provided two different versions of the Circuit Wizard files; one for the education version and one for the standard version (as supplied by *EPE*). In addition, some parts will have additional files for download (for example, templates for laser cutting)
- ***Get real*** – introduces you to some interesting and often quirky snippets of information that might just help you avoid some pitfalls
- ***Take it further*** – provides you with suggestions for building the circuit and manufacturing a prototype. As well as basic construction information, we will provide you with ideas for realising your design and making it into a complete project
- ***Photo Gallery*** – shows how we developed and built each of the projects.

Coming attractions

Issue	Topic	Notes
May 2012 ✓	Moisture alarm	Get ready for a British summer!
June 2012 ✓	Quiz machine	Revision stop!
July 2012 ✓	Battery voltage checker	For all your portable gear
August 2012 ✓	Solar mobile phone charger	Away from home/school
September 2012 ✓	Theft alarm	Protect your property!
October 2012	Wailing siren, flashing lights	Halloween "spooky circuits"
November 2012	Frost alarm	Beginning of winter
December 2012	Mini Christmas lights	Christmas
January 2013	iPod speaker	Portable Hi-Fi
February 2013	Logic probe	Going digital!
March 2013	DC motor controller	Ideal for all model makers
April 2013	Egg Timer	Boil the perfect egg!
May 2013	Signal injector	Where did that signal go?
June 2013	Simple radio	Ideal for camping and hiking
July 2013	Temperature alarm	It ain't half hot ...

Theft Alarm

In this month's Jump Start *we shall be designing and building a* Versatile Theft Alarm *that will help you protect your valuable possessions from theft. The unit can be used with a variety of different sensors and can provide both visual and audible alarm indications.*

Under the hood

Our *Versatile Theft Alarm* is designed to provide a solution to the increasing need to protect your valuable belongings from damage and burglary. The alarm provides both visual and audible outputs and, once activated it will remain operating until the supply is switched off by means of a keyswitch. It is designed for internal (rather than external) use and it can derive its power from batteries or a commonly available 9V DC power adapter capable of supplying 200mA, or more.

The simplified block schematic of our *Versatile Theft Alarm* is shown in Fig.1. The circuit provides for two

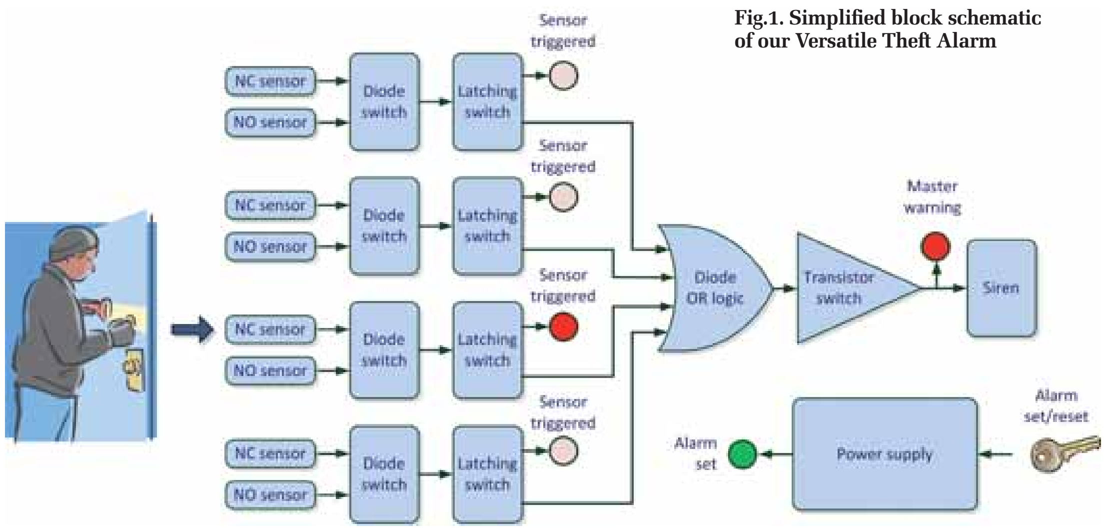


Fig.1. Simplified block schematic of our Versatile Theft Alarm

different types of sensor; those that act like normally closed (NC) switches, *opening* when activated, and those that operate as normally open (NO) switches, *closing* when activated. This ensures that the unit can be used with a very wide range of sensors, including pressure mats, microswitches, magnetic reed switches, and a variety of different contact arrangements.

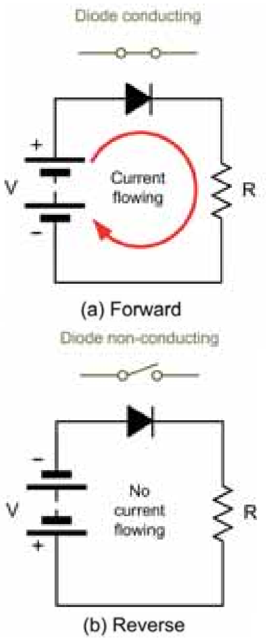


Fig.2. A diode in forward/conducting and reverse/non-conducting states

The outputs from the sensors are combined using a diode switching arrangement (more of this later) and then fed to a silicon controlled rectifier (SCR), which acts as latching switch so that, when triggered, the alarm signal remains active regardless of the state of the sensors. The four channels are then combined in a simple OR-logic arrangement which provides an output whenever one or more of the SCRs become triggered into a conducting state.

Finally, the output from the OR-logic is fed to a saturated transistor switch, which provides sufficient current to drive a small piezoelectric siren. The circuit is set and reset by interrupting the supply using a key-operated switch.

Design notes

This edition of *Jump Start* introduces a few circuit techniques that we haven't seen before. Notable among them is the use of diodes as switches, and also as a means of performing simple logic operations.

Diodes as switches

When the anode of a diode is made positive with respect to the cathode the diode will conduct, acting like a closed switch, as shown in Fig.2(a). Conversely, when the anode of a diode is made negative with respect to the cathode, a conventional diode will not conduct, acting like an open switch, as shown in Fig.2(b). This directional property leads to a number of useful practical applications, including rectifiers and simple switching circuits.

In the real-world, diodes are not perfect devices and, when conducting, they have a small amount of resistance. For a small silicon switching diode, such as a 1N4148, operating with a forward current of 1mA this might amount to several hundred ohms. The same diode, operating with a reverse voltage of 10V applied would typically have a reverse resistance of several tens or hundreds of millions of ohms. Table 1 provides a comparison of the performance of a 1N4148 diode with a perfect switching device. You can easily check this out using the Circuit Wizard.

To check the forward resistance of a diode we need to apply a known value of constant current to the device and then measure the forward voltage dropped across it, as shown in Fig.3. The values of forward voltage drop and applied current can then be used

Table 1: Comparison of a 1N4148 signal diode with a 'perfect' switching device

	Forward resistance		Reverse resistance	
	I_F = 1mA	I_F = 5 mA	V_R = 10V	V_R = 50V
1N4148 silicon diode	612Ω	143Ω	Very high (almost infinite)	338MΩ
Perfect switch	Zero		Infinite	

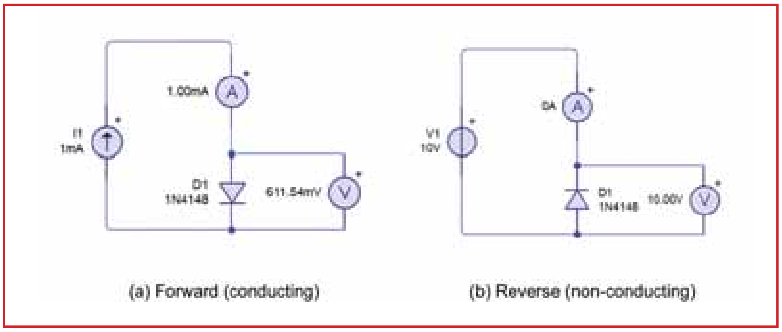


Fig.3. Using Wizard to check the performance of a diode when acting as a switch

in a simple Ohm's law calculation in order to determine the forward resistance, R_{FWD}, as follows:

$$R_{FWD} = \frac{\text{Forward voltage drop}}{\text{Applied forward current}} = \frac{V_F}{I_F}$$

To determine the reverse resistance of a diode we need to apply a known value of voltage to the device and then measure the reverse current flowing in it, as shown in Fig.4. The values of reverse current and applied voltage can similarly be used in a simple Ohm's law calculation in order to determine the reverse resistance, R_{REV}, as follows:

$$R_{REV} = \frac{\text{Applied reverse voltage}}{\text{Reverse current flowing}} = \frac{V_R}{I_R}$$

In order to perform these measurements based on Circuit Wizard's model of a 1N4148 diode it is first necessary to set the diode properties. Click on the diode symbol in 'Circuit View' and then select '1N4148' from the drop-down list in the 'Diode Properties' dialogue box, as shown in Fig.4.

When measuring the forward resistance of the diode, it is necessary to select a forward current to apply to the diode. This can easily be done by clicking on the current source symbol in Fig.3a and then selecting a suitable value of forward current (for example, '1mA') from the drop-down list in the Current Source Properties dialogue box, as shown in Fig.5.

Similarly, when investigating the reverse resistance of the diode you will need to select a reverse voltage to apply to the diode. This is, once again, easily done by clicking on the voltage source symbol in Fig.3b and then selecting a suitable value of reverse voltage current (for example, '10V') from the drop-down list in the Voltage Source Properties dialogue box, as shown in Fig.6.

The values that we obtained when we made these measurements are shown, along with those that would apply to a 'perfect' switching device, in Table 1. Note how the forward resistance of the diode falls significantly with an increase in forward current and also how the reverse resistance of the diode is extremely high, even when the applied reverse voltage increases to 50V.

Fig.7 (right). Diode switch enabling both types of sensor (NO and NC), to be used to activate an alarm

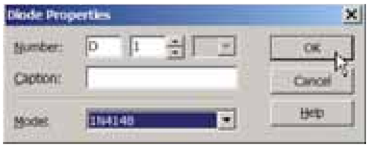
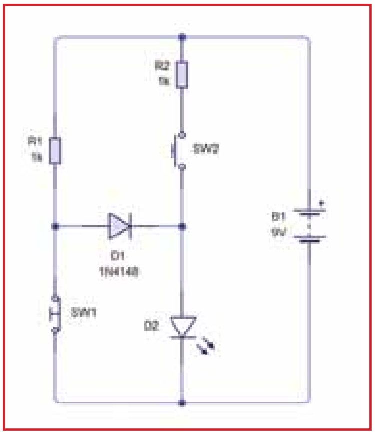
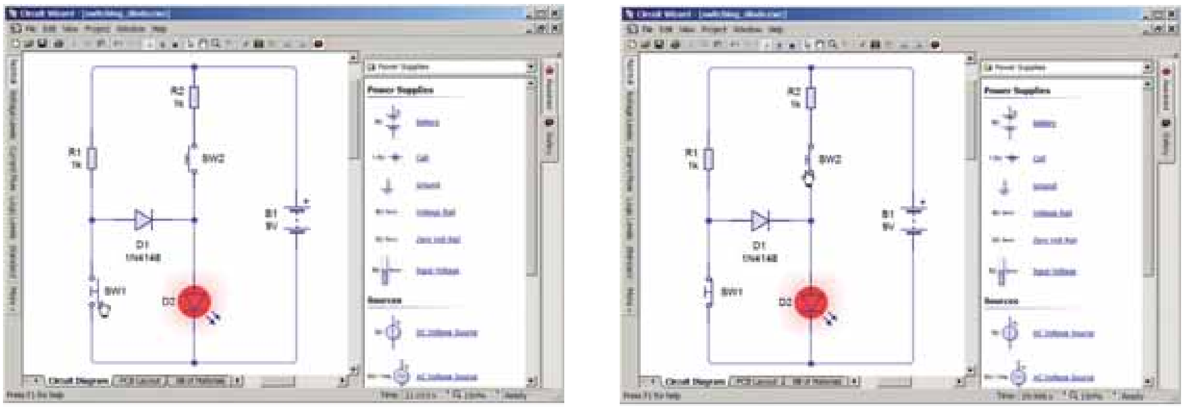


Fig.4. Setting the diode properties so that Circuit Wizard uses the correct model for a 1N4148 device

Fig.5. Setting the Current Source Properties in Fig.3a

Fig.6. Setting the Voltage Source Properties in Fig.3b





(a) Using the NC switch (SW1) to activate the alarm

(b) Using the NO switch (SW2) to activate the alarm

Fig.8. Testing the diode switch in Circuit Wizard (a) using the NC switch to activate the alarm and (b) using the NO switch to activate the alarm

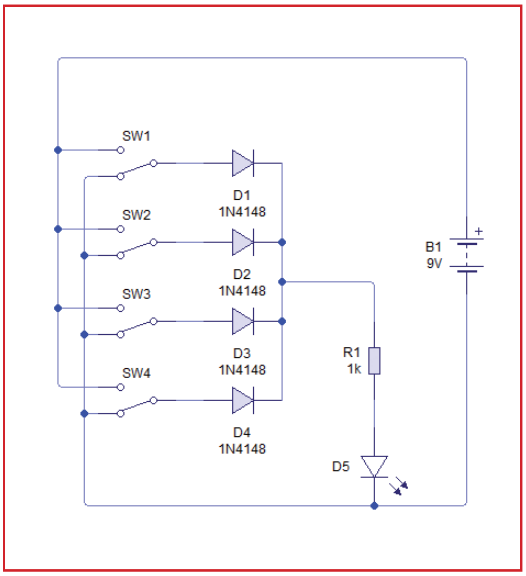


Fig.9. Diode logic: a four-input diode OR circuit in which taking any one or more of the inputs to the positive supply rail will activate the LED indicator

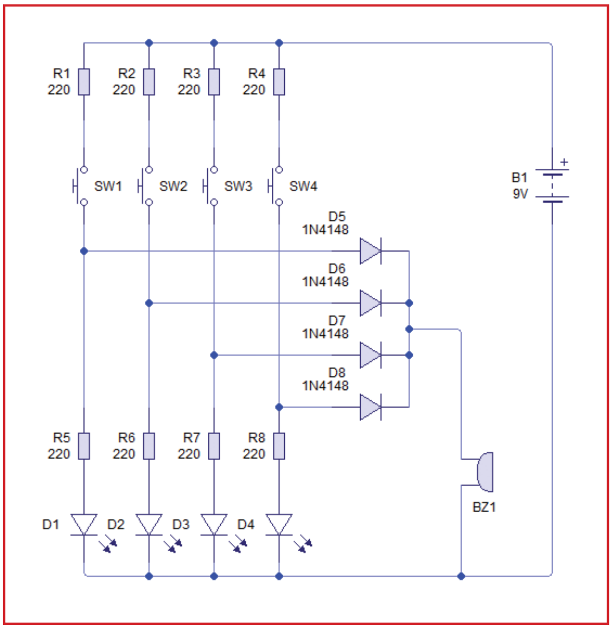


Fig.10. A simple alarm circuit simulated using Circuit Wizard

Practical diode switching arrangement

One of the basic requirements of our *Versatile Theft Alarm* is that it should be capable of operating in conjunction with both types of switch sensor ie, those with contacts that are normally open (NO) and become closed when activated, and those that have contacts that are normally closed (NC) and become open when activated.

These two conflicting requirements can be easily satisfied by using a circuit based on a diode switch, like that shown in Fig.7. The diode switching circuit can easily be tested in Circuit Wizard, as shown in Fig.8.

Latching action

Our alarm circuit has four separate inputs (each one being triggered by either an NO switch or an NC switch). So that the alarm is held 'on' when triggered, and also so that the user knows which of the input circuits has been triggered, four silicon controlled rectifiers (SCR) are used to provide the necessary latching action.

This arrangement also ensures that the alarm cannot simply be defeated by returning the sensor to its original state or by cutting the wires to the sensor! Once triggered, into conduction by the application of a small trigger current to the gate each SCR will remain in the conducting state until the alarm is switched off. We have previously described the operation of this type of circuit based on SCRs, so no further comment is required here.

Diode logic

Having provided for a latching visual indication on each of the four input circuits, our final objective is that of combining the four input signals so that, when activated, any one (or more) of them will activate the audible alarm.

This can be achieved by means of a circuit based on simple diode logic, as shown in Fig.9. We've used Circuit Wizard to illustrate this circuit so you can easily give it a try and confirm that it really does work.

Get real

A simple yet functional four-input alarm circuit (without latching action) is shown in Fig.10. In this arrangement we have used only normally open (NO) pushbutton switches to simulate the four sensor inputs.

A note regarding Circuit Wizard versions:

Circuit Wizard is available in several variants; Standard, Professional and Education (available to educational institutions only). Please note that the component library, virtual instruments and features available do differ for each variant, as do the licensing limitations. Therefore, you should check which is relevant to you before purchase. During the Jump Start series we aim to use circuits/features of the software that are compatible with the latest versions of all variants of the software. However, we cannot guarantee that all items will be operational with every variant/version.

Each switch has been given its own LED indicator. The output of the diode OR-logic is then taken to a buzzer which will sound when any one or more of the pushbutton switches is pressed.

The circuit shown in Fig.10 makes a good starting point for further development. To this we must add the additional diode circuitry to permit the use of normally-closed (NC) sensors and four silicon controlled rectifiers to provide the necessary latching action. Finally, since we need our circuit to provide sufficient output to drive a miniature piezoelectric sounder a further stage will be required in the form of a saturated transistor switch.

The next section shows how we used Circuit Wizard to solve these problems!

Versatile Theft Alarm – using Circuit Wizard

Our practical *Versatile Theft Alarm* circuit diagram is shown in Fig.11. As you can see, we've used a clever arrangement of thyristors and diodes to achieve a four 'zone' alarm system. So let's look at its basic operation. Circuit Wizard does a really nice job of simulating the circuit. Take care to enter the circuit accurately, especially where lines (wires) cross.

Note that if you run a wire across the end of a component it will add a connecting node automatically (whether you wish it to be connected or not). Therefore, give yourself enough space around components when laying them out.

What's going on?

Although strictly speaking it's not a digital circuit, Circuit Wizard's 'logic level' view is really helpful here to quickly see what's going on in the circuit (Fig.12).

The normally closed inputs (SW1 to SW4) hold the input to their corresponding thyristors low, until they open and trigger the thyristor for that zone. Similarly, when the normally open inputs (SW5 to SW8) are closed, the thyristor for that zone is activated.

Experiment with pressing the switches and note how the various lines are affected (remember that 'high' is shown as red and 'low' as green in this view). When converted to a PCB all of the switches will become two-pin screw terminals permitting connection of various external sensor inputs (see Fig.14).

The output siren and LED indicator are driven by Q1, which is turned on by any of the four zones being triggered via a diode-based 'OR' gate. The BC639 is capable of driving a modest siren which could be mounted internally (as in our prototype) or externally. If you require a more powerful output you could easily amend the output stage with a medium-power transistor or a relay.

Power supply wise, the circuit may be tested using a PP3 battery, but in operation you should consider a higher capacity battery or a small mains adapter for prolonged use. The circuit should operate happily between 6V to 9V, with an untriggered working current of about 5mA to 10mA.

Sensors

Each of the four zones may be triggered by either a normally open or normally closed sensor input, although there are opportunities for further customisation. Typical normally closed sensor inputs might include magnetic reed switches (attached to a window, door or other opening – see Fig.13), glass break wires or trip wires.

Normally closed inputs might include pressure pads or panic buttons. PIR or passive infrared sensors that you might see in a commercial alarm system could

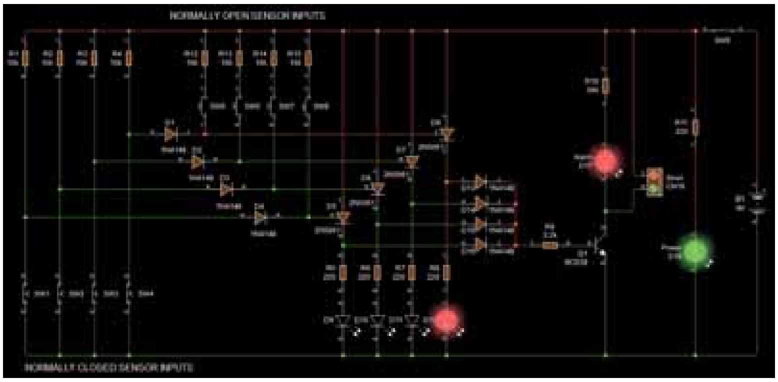


Fig.12. Using Circuit Wizard's 'logic level' view to quickly see what's going on

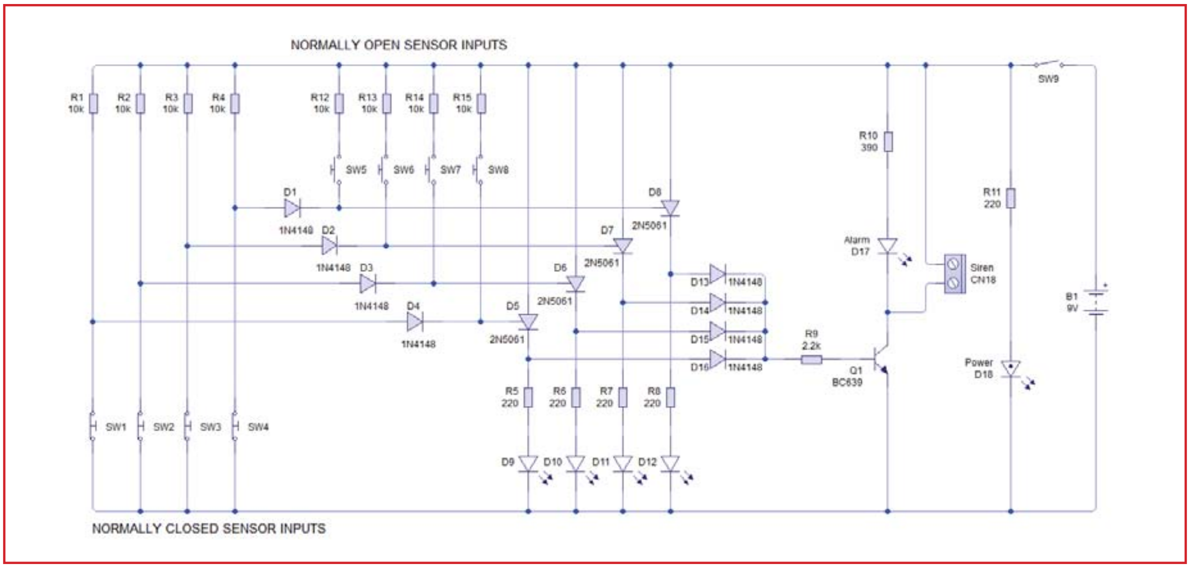


Fig.11. The finalised *Versatile Theft Alarm* practical circuit diagram, displayed using Circuit Wizard

also be used. These often have relay or transistorised outputs (either NC or NO), but will also require power supply lines.

The way that you choose to configure the alarm depends on its intended purpose. Note that if you intend to use a normally open input, you will need to add a link to the corresponding normally closed input (Fig.14). It is also theoretically possible to have additional sensors for each zone.

In the case of adding additional normally closed sensors to a zone, they would need to be wired in parallel and for normally closed in series. In this way, any of the sensors would activate the alarm for that zone. It is also possible to have a combination of NO and NC sensors controlling one zone.

Construction

Creating a PCB for this circuit may be a little more challenging than previous circuits in the series, due to its complexity. It's quite achievable, but you can expect it to take time to get right.

Our top tip is to look carefully at the way the components are arranged and oriented to facilitate the easiest routing of tracks. Make sure that you get this right *before* you endeavour to add any tracks or auto-route, as it will save you a lot of aggravation later on.

You may need to add some wire links to achieve 100% routing. In fact, we added two on ours. Adding links is really easy; first add two pads where you wish to start/finish your link, then select the 'flying wire' tool from the 'Layout Tools' drop down and simply draw in the link wire clicking the first and second pads in turn (see Fig.15). Circuit Wizard will take into account any links when it carries out quality control checks. As a general rule, try to keep links to a minimum, as small as possible and only vertical or horizontal. Never run a link over or close

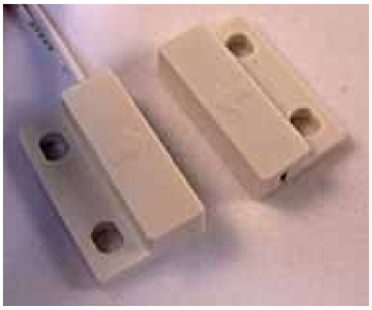


Fig.13. An enclosed magnetic reed switch

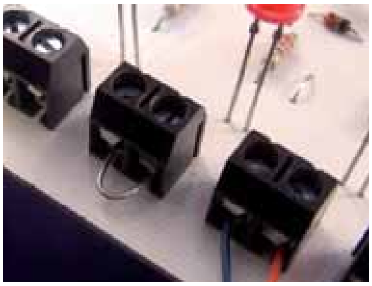


Fig.14. Adding a link for a normally open (NO) input

to components as they could short, as well as looking rather unattractive.

Virtual testing

Once you've got your PCB designed, why not do some virtual testing? Fig.17 shows our prototype PCB design being tested using two push-to-make buttons to simulate normally open inputs on zones A/B, and two push-to-break

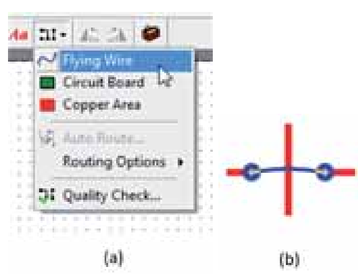


Fig.15 (left). Adding a link to achieve 100% routing

You will need...

1 PCB, code 867, available from the *EPE PCB Service*, size 112mm × 84mm
1 ABS grey case with recessed base, 175mm ×145mm × 60mm (Rapid 30-3550) (**www.rapidonline.com**)
1 6V to 12V 100mA mini piezo siren (Rapid 35-3538)
10 2-way PCB mounting terminal blocks
1 9V 200mA minimum DC mains power supply (for normal operation)
1 miniature keyswitch
1 9V (PP3) battery, plus clip and leads (for test purposes)
4 normally closed (NC) sensors (SW1 to SW4, as required)
4 normally open (NO) sensors (SW5 to SW8, as required)
4 threaded PCB mounting pillars

Semiconductors
1 BC639 *NPN* transistor
8 1N4148 signal diodes (D1 to D4 and D13 to D16)
4 2N5061 silicon controlled rectifiers (SCRs) (D5 to D8)
5 5mm red LEDs (D9 to D12 and D17)
1 5mm flashing green LED (D18)

Resistors
8 10kΩ (R1 to R4 and R12 to R15)
5 220Ω (R5 to R8 and R11)
1 2.2kΩ (R9) 1 390Ω (R10)

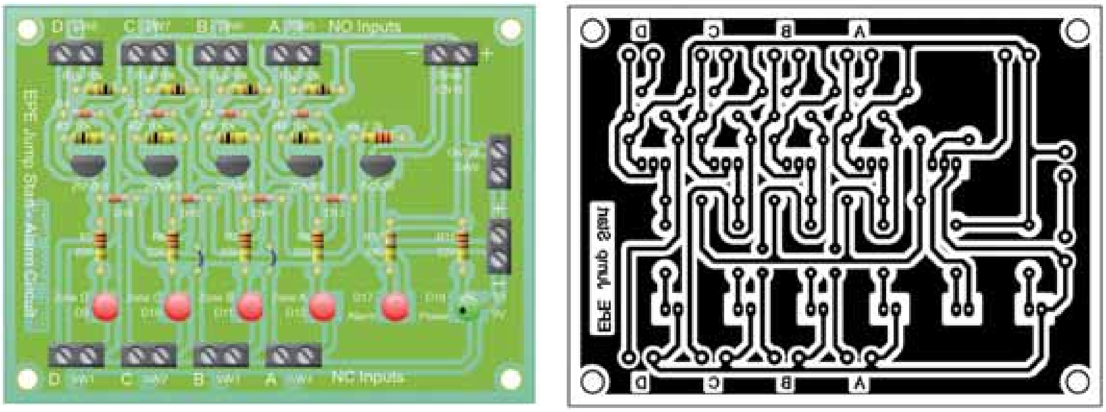


Fig.16. PCB artwork showing real world and PCB views. The final size of the prototype board is 112mm × 84mm

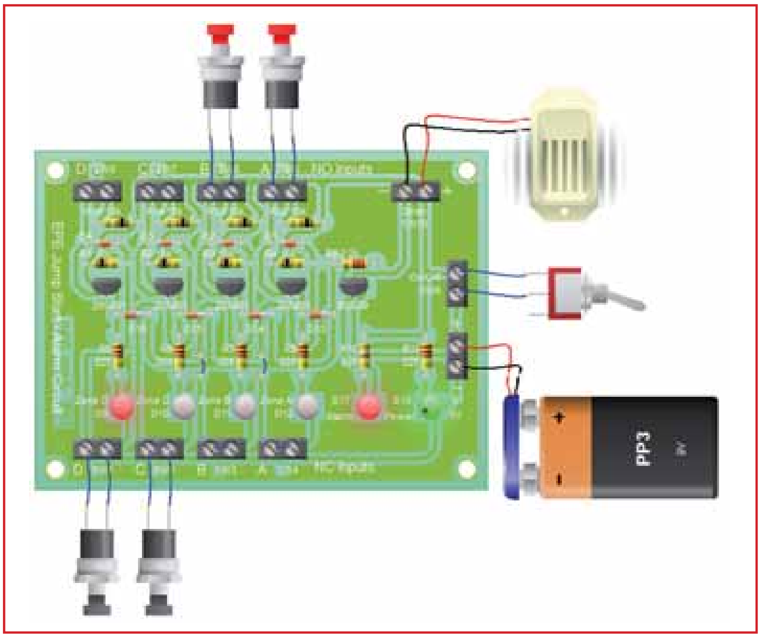


Fig.17. The printed circuit board (PCB), component layout for the Versatile Theft Alarm being 'tested' virtually in Circuit Wizard

Fig.18. A mini 6V to 12V 100mA piezoelectric siren

Fig.19. A small keyswitch is ideal for turning the alarm on and off

switches simulating normally closed inputs to zones C/D. As discussed earlier, we added link wires to SW3/4 to avoid persistent triggering of zones A/B.

We mounted our prototype circuit in a pre-manufactured ABS enclosure suitable for wall mounting and allowing enough space to mount a small siren unit (Fig.18) inside. The PCB was mounted on metal threaded hex spacers and the LEDs fitted such that they located into 5mm holes drilled in to the front facia. Take some time to ensure that your holes are drilled accurately and your LEDs mounted at the correct level to ensure good alignment. A key switch (Fig.19) was installed and connected to SW9 to turn the alarm on/off securely.

We 'recycled' a telephone extension cord to connect our external sensors. Multi-stranded signal cable or network cable could also be used for this purpose. Do take care when preparing such cables, the conductors are easily cut when stripping. So, whether you're securing a stash of biscuits in a cupboard or locking down your hi-tech gadgets in your home workshop, the circuit can be tailored to your meet your individual security needs!

Next month

In next month's *Jump Start* we will be developing some 'spooky circuits' that will help you celebrate Halloween in style – see you next month!

Photo gallery...

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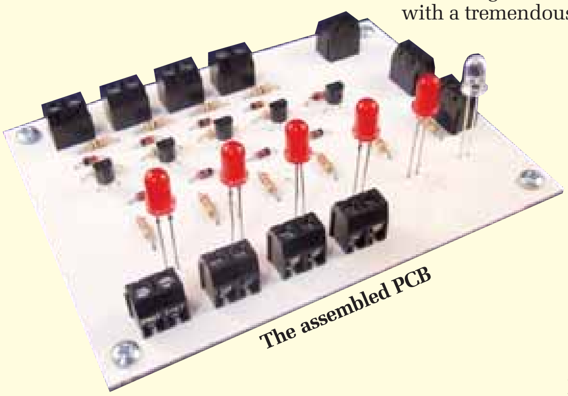
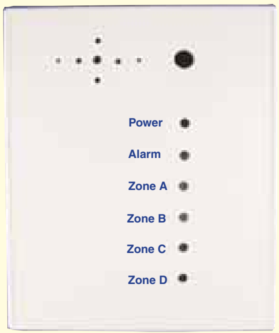
www.tooley.co.uk/epe

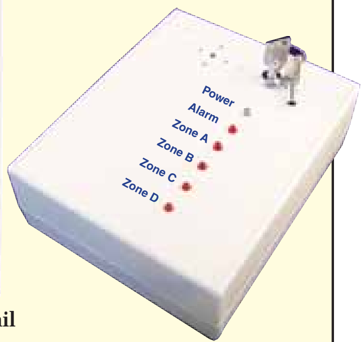
The Gallery is intended to show readers some of the techniques that they can put to use in the practical realisation of a design. This is very important in an educational context, where learners are required to realise their own designs, ending up with a finished project that demonstrates their competence, skills and understanding. The techniques that we have used are available in nearly every secondary school and college in the country, and we believe that our series will provide teachers with a tremendously useful resource!



The assembled PCB



Front panel hole drilling detail



The finished alarm unit

Special thanks to Chichester College *for the use of their facilities when preparing the featured circuits.*

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Raspberry Pi

A battery-backed Real-Time Clock

Time for some Pi
By
Mike Hibbett

IN CASE you're still wondering, the Raspberry Pi is an extremely low cost computer, designed by a small charitable foundation in Cambridge, UK. It's the brain child of Broadcom designer Eben Upton, who worked on the very processor used in the Pi – the Broadcom BCM2835.

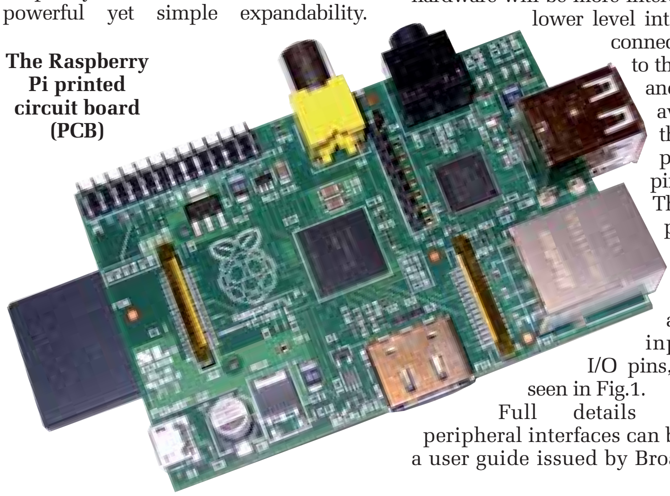
The Pi was conceived to regenerate a fundamental interest in computing in children, in much the same way that the Sinclair Spectrum and the BBC Micro computer did in the 1980s.

Value for your money

For a little over £25 (£36 from Farnell, £31 from RS Components), you get the computer in its rawest form – a printed circuit board without keyboard, display or even a case. However, this is a very powerful computer, for its price – a 700MHz processor, 256MB of SDRAM, and a built-in graphics accelerator capable of rendering high definition video at 1080p through its built-in HDMI interface.

Main attractions

One of the main attractions of the Raspberry Pi (after its low cost) is it's powerful yet simple expandability.



The Raspberry Pi printed circuit board (PCB)

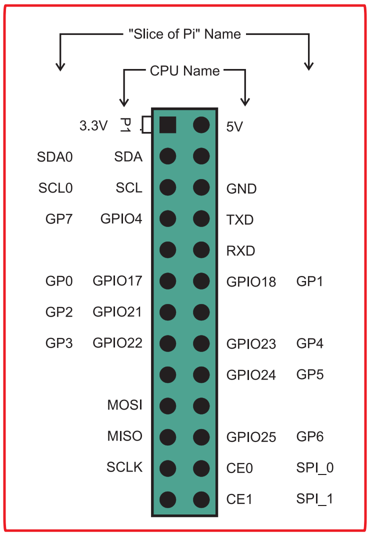


Fig.1. I/O pin designations

While many users will be satisfied with the dual USB interfaces to which standard peripherals can be attached, those of us who love to build our own hardware will be more interested in the lower level interfaces that connect directly to the processor and are made available on the 0.1-inch pitch 26-pin header. This header provides access to the SPI, I2C, UART and general input/output I/O pins, as can be seen in Fig.1.

Full details of these peripheral interfaces can be found in a user guide issued by Broadcom, the CPU manufacturer. Unlike Microchip, who provide complete processor specifications for their chips, Broadcom are very secretive about the inner workings of the processor and the user guide on the peripherals is the full extent of the information the general public can expect from them.

Fortunately, this only affects the people developing the operating system and video output capabilities; for us hardware tinkerers, the peripheral interface document will suffice. See Ref.1 for the download location.

Inputs/outputs

As you might expect for a complex microprocessor, the peripherals are complex and difficult to configure. However, the digital I/O ports are (relatively) simple to set up, so our first hardware project, while providing a useful piece of missing functionality, has been chosen to be achievable with digital I/O alone. By default, there are eight I/O pins available on the header, which will be more than enough for our needs.

Just like our friend the PIC processor, the I/O pins on the Pi can have multiple functions, so while there are SPI, I2C and UART function pins on the header, all of these can be turned into general purpose digital I/O pins if required, adding a further nine I/O lines. We will explore the serial communication capabilities in future articles, and also look to address the lack of analogue sensing capabilities.

Connecting it up

Before we talk about how to wire up to the board, a word of warning: All of the I/O pins are designed **to run at 3.3V only**. With 5V available on the header, you might be tempted ask whether you can hook up some 5V devices; the simple answer is: *do not*. The Pi processor is a delicate creature, and 5V applied to any

input will almost certainly destroy it in an instant. Potential dividers or voltage level shifter ICs can be used to interface 5V logic to the Pi, but that increases the complexity and power consumption; we will avoid this issue altogether by simply designing our circuit to run at 3.3V

So, how should one connect wires to the board? We strongly recommend against soldering to the header pins as this can weaken the tracks on the PCB and increase the risk of shorts occurring. A far better solution is to purchase a 2×13, 0.1-inch pitch socket (or a longer one, that you can cut down.) you can then solder wires to this socket, and simply replace it if necessary. As the header is on a standard 0.1-inch pitch, the work required to create a daughter board is significantly reduced – you can purchase stripboard with square pads on a 0.1-inch pitch, and etching your own boards is not particularly difficult if you have access to a UV eraser.

Slice of Pi

Fortunately, there is an even simpler way to construct small daughter boards by using a prototyping board designed specifically for the Raspberry Pi. There are a number available on the market already, and one of the more popular ones is the 'Slice of Pi', available from Ciseco in the UK for £3.90.

This works out as excellent value, as they supply the board with all the connectors you could possibly need. The board can be purchased from the website address shown in Ref.2, but they also sell it on eBay. What you get for your £3.90 is shown in Fig.2.

Besides the required 2×13 socket (which you must solder onto the board yourself) there are other sockets to provide 'Arduino like' interfaces to the I/O pins, should you wish. It's a great price and ideal for small interfacing projects. We bought several.

It should be noted that text printed on the board to indicate pin functions does not quite match the I/O pin functions on the Pi's header, which confused us at first. Fig.1 shows the translation between the text printed on the Slice of Pi PCB and the true processor functions.

Controlling the Pins

So how do we go about controlling these I/O pins?

At the moment, there are two choices: Using the Python programming language, or C. Python as installed on the default SDMedia card image cannot access the pins directly, but a Python module called RPi.GPIO (itself probably written in C) has been developed to provide a simple, if very slow, interface. For the purpose of this month's article, that would be perfectly suitable, but it does require finding, downloading and correctly installing the module, which can be quite difficult. The

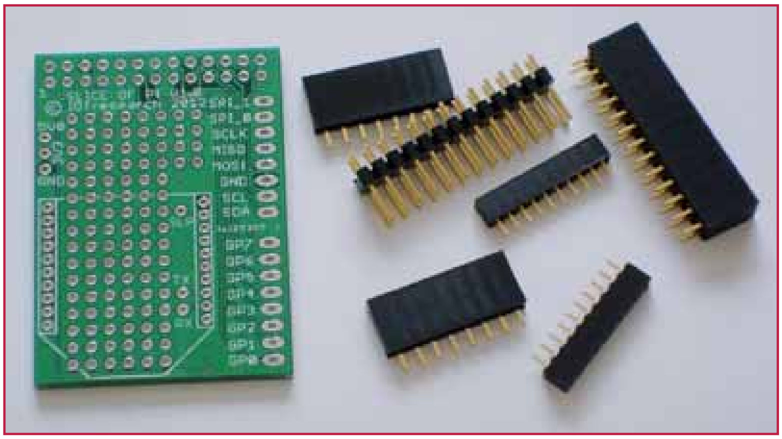


Fig.2. Slice of Pi prototyping board and connectors

RPi.GPIO module is in early stages of development and the intention is that it will support the other serial interfaces, so it's certainly an interesting project to keep an eye on and may one day find its way into the standard SDMedia card image. You can read more about it at the project website, the address of which can be found in Ref.3. For now, we will use the C programming language.

Programming in C

One of the joys of having a powerful hardware platform like the Pi is the ability to do 'target-based development' – writing software on the very target you intend to run it on. While people developing software on Windows PCs will consider this the norm, for us hardware tinkerers used to writing software for tiny PIC processors, this approach comes as something of a novelty.

No installation or setup is required to be able to compile C programs on the Pi; it comes pre-installed and ready for use out of the box. This is part of the Linux ethos; unlike the Windows operating system, which is designed for commercial or 'home' use, Linux was designed for people like us, and development tools are provided as standard. The C compiler is only one of hundreds of programmer utilities that are available; it would take a book to explain them all (many of which do exist.)

The C programming language is the obvious choice for controlling low-level chip functions when high speed or small code size are important. Neither of those are true in this month's article, but this approach is the easiest to demonstrate, so it's the approach we shall take.

Real-time Clock

Let's get down to the nuts and bolts of this month's article – constructing a battery-backed real-time clock.

On any normal personal computer, be it a laptop, desktop or tablet PC, a standard feature is a battery-backed real-time clock or RTC. It's been several decades since this became the norm; the Raspberry Pi, however, does not come with one fitted.

This is for two reasons; first, as a small cost saving, and second as the computer is normally going to be connected to the Internet from which the current date and time can be determined. Not all uses of the Pi will include permanent Internet connectivity, so it seemed a good choice that our first project should provide this bit of essential functionality.

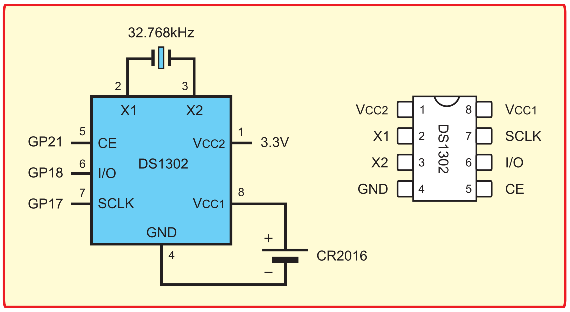


Fig.3. Real-time clock circuit diagram (if you can call it that)

Hardware

Unsurprisingly, since a battery-backed real-time clock has been an essential feature for decades, there are are a multitude of low cost integrated circuit solutions to this problem. We chose the Dallas DS1302 IC, for a number of reasons. It's a common readily available part, runs at 3.3V, is available in an 8-pin DIL package, has a simple serial interface and requires only a battery and a 32kHz crystal to operate. The full circuit, if one can call it that, can be seen in Fig.3.

The DS1302 can work with a rechargeable battery without additional components, but we have chosen to go

Shopping Cart

Real-time Clock

1 DS1302 8-pin 3.3V counter/serial interface (Farnell code 1188041)
1 32kHz crystal (Farnell 1641085)
1 3.3V CA2016/CR2032 lithium button cell
1 button cell holder (Farnell 676469)
1 slice of Pi prototyping 'daughter' board, with connectors (ciseco: www.ciseco.co.uk)
Coloured plastic-covered 'hookup' wire

Plus

1 Raspberry Pi, low-cost, single circuit board 'computer' – see text (www.Raspberrypi.org)

Farnell: uk.farnell.com

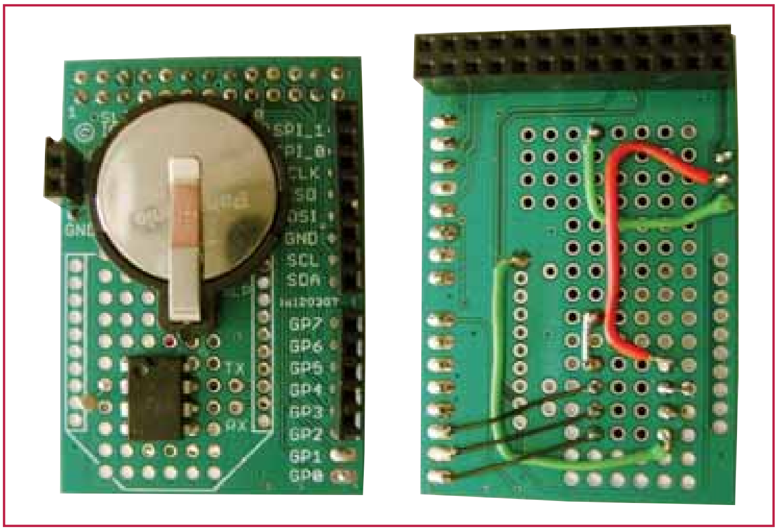


Fig.4. The assembled time clock topside (left) and underside (right)

with a standard lithium button cell, the CR2016/CR2032. This is a cheap battery and should last for several years, so the extra cost of a rechargeable battery was not considered necessary. With this being such a simple circuit, we took the slightly unusual step of not using an IC socket. Let's throw caution to the wind for a change!

Apart from the 'Slice of Pi' prototyping board, the components required are listed in the 'Shopping Cart' above. Farnell part numbers are given as examples; as these are common parts, you should be able to source them from other suppliers.

The total cost of the Farnell parts amount to just over £10. It's interesting to note that such a simple piece of functionality costs more than a third of the price of the computer itself!

The DS1302 is little more than an accurate counter, formatting the count in a standard date and time format in a series of registers accessible via a simple SPI-like interface. The IC does handle leap years correctly, and also provides a 32-byte 'scratch pad' area of battery-backed RAM – although as we have the entire SDMedia card at our disposal, there isn't much use for this.

Construction

Construction is very straightforward with just a little thought about positioning of components required to allow space for accessing some of the spare I/O pins. Be careful with the orientation of the battery holder, both in terms of the polarity and locating it so that the battery can be easily removed.

Our layout can be seen in Fig.4. Low-current hookup wire can be used with point-to-point wiring; thicker wire provides a little extra physical stability. Once the software had been developed, and the board fully tested, we applied a thin layer of hot-melt glue to the wires to provide a little extra mechanical stability; without an enclosure this board will be exposed to some rough handling.

Software

Let's now move on to the software design. The first issue to address is how we want to access and control the IC. We will keep things simple, and look to create a utility that can do just two tasks: set the date and time within the chip, or read it back, automatically updating the Pi's clock. We are going to create a simple utility program – let's call it **rtc-pi**, that can be called in one of two ways to accomplish these tasks.

Without any command line arguments, the program will read the time and date from the DS1302 and update the Pi's clock:

rtc-pi

To set the clock, specify the date and time as a single string of digits in 24 hour clock format:

rtc-pi 20120714185400

The string of numbers should be specified in a fixed format, CCYYMMDDhhmmss. With that simple specification we can look at how our software will access the DS1302. The datasheet (available for download from the Farnell website) indicates a very simple serial interface: raise the CE pin high, set a data bit on the IO pin, then toggle the SCLK pin to latch the data bit into the chip. Repeat a further seven times to transfer a byte. To read a data byte from the device, turn the Pi pin connected to the IO pin into an input, lower the SCLK pin, read the level on the IO pin and then raise the SCLK pin high. Repeat seven times to extract a full byte.

Careful examination of the last few pages of the datasheet reveals the usual caveat: small delays must be allowed between changing the level of the SCLK pin and reading or setting the data pin. This is quite normal, and the delays required are quite short. As we will be transferring at most 12 bytes of data, we can be fairly cavalier with the time delay, and so we use the built-in usleep() C function to provide a 2μs delay where needed.

There are just six, one-byte registers to read or write; each byte can be addressed individually, so we have produced two functions to handle the low-level communications (one to read a byte from a specified address, one to write a byte.) If you take a look at these functions in the **rtc-pi.c** source code (available for download from the *EPE* website,) they will look very familiar to a similar program written for a PIC processor. And so they should; the C code itself is quite portable.

Inputs and/or outputs

It's now time to look at how we configure the Pi's digital I/O pins for use, and this is the point where things start looking different. Very different indeed!

Just like the PIC processor, the Pi's CPU has I/O control registers that are 'mapped' into RAM memory locations. Unlike the PIC, however, the Pi's processor uses a memory management unit with the CPU to restrict access to memory.

A program running in it's own restricted area of memory must ask the operating system for permission to gain access to the peripheral registers. This is done with the mmap() system call. The call asks the operating system to map a section of the peripheral memory *into* the program's own memory area – hence the need to allocate, through a malloc call, a section of RAM to act as an interface to the peripheral registers. Although strange, this is standard

practice on processors with powerful operating systems such as the Pi's.

Having mapped the peripheral registers into our program's memory, only four registers need to be accessed to fulfill our needs: GPFSEL, to set the pin to an input or an output; GPSET, to set a pin to a high level; GPCLR, to set a pin to a low level; and GPLEV, to read the current state of an input pin. The macros at the beginning of the source file translate the twiddling of these registers into simple-to-understand names (which also simplifies changing the code to use different digital I/O pins, if required.)

Fig.5. The Pi real-time clock in action

Clock update

The remaining unusual function call within the code is the system() call, used to update the Pi's clock. This is a request from the program to the operating system to execute a command, as though typed on the command line by a user.

Again, unlike software written for the PIC processor, our programs no longer operate in isolation – our code must interact with the operating system to get 'real-world events' done, such as toggling physical pins or changing the clock. Although a little difficult to get used to, it does allow the operating system to isolate running programs from each other, avoiding a single rogue program from bringing the whole system down. And under Linux, this works quite well.

Building the code

To build the code, copy the single source file rtc-pi.c on to the Pi, to the Desktop (a USB memory stick is ideal for this.)

Open up a terminal window and type the following commands:

```
cd Desktop
cc rtc-pi.c
mv a.out rtc-pi
chmod +x rtc-pi
```

The cc command compiles and links the code, creating an output file called a.out. The mv command renames a.out to something more meaningful, and the chmod command changes the mode of the file to allow it to be executed. Now to use the file, run it as follows:

```
sudo ./rtc-pi CCYYMMDDhhmmss
```

to set the date in the DS1302, or

```
sudo ./rtc-pi
```

This will read it back from the IC and update the Pi's realtime clock.

You might notice that the time shown on the display is not updated immediately, but on the next minute 'tick'. This is just the way the Pi's 'Window Manager' works, reducing the amount of processing time it takes from the CPU. The clock is updated immediately, which you can confirm by typing the 'date' command in a terminal window.

Fig.5 shows the board in use, coupled with the Maplin wireless mini keyboard and mouse. For the price, this combo is a great deal, frees up a USB socket and is a very tidy solution. Our children love it. It's not ideally suited to touch typing, but it is ideal for web browsing and light work. The part code is N69JX.

References

Ref. 1 *Peripheral User Guide* www.raspberrypi.org/wp-content/uploads/2012/02/BCM2835-ARM-Peripherals.pdf

Ref. 2 *Slice of Pi Supplier* http://shop.ciseco.co.uk/slice-of-pi/

Ref. 3 *RpiGPIO Python Module* http://pypi.python.org/pypi/RPi.GPIO/

PIC n' Mix

Mike Hibbett

Our periodic column for PIC programming enlightenment

Starting out with PICs

When writing software for the PIC processor for the first time, there are a number of hurdles that can catch out the unfamiliar. While there are many tutorials available on the Internet, we see the same questions coming up on support forums: 'How do I use Interrupts?', 'What are the Configuration Bits?', 'My code isn't running – is it my program or the hardware?' Whether you are new to programming or moving into the field from PC-based languages like BASIC these are quite reasonable questions, as programming for embedded systems using small microcontrollers comes with a number of quirky features. Features that are specific to the processor of choice. The PIC, arguably, has more than it's fair share!

Over the next few months we will explore some of these issues and, hopefully, simplify the process of getting a project started, passing these hurdles so you can get to the fun part.

For the benefit of as many people as possible we are going to start from basics, and work through some examples with a single, low cost processor – the PIC18F27J13. We will start with a very simple circuit and build it up into a very low cost general purpose development board (with a target cost under £10.) Following this we will move into a tutorial on programming the processor in 'C'.

Overview

Let's start by getting an overview of the processor from its datasheet, 39974A.pdf, available from the Microchip website. The processor is available in our favorite 28-pin DIL format (pinout shown in Fig.1,) and surface mount for the more daring. It has 128KB Flash memory providing for over 65,000 instructions, and 3760 bytes of RAM. 19 I/O pins, four timers and the usual ADC, SPI, I2C and UART peripherals provide for a wide range of applications.

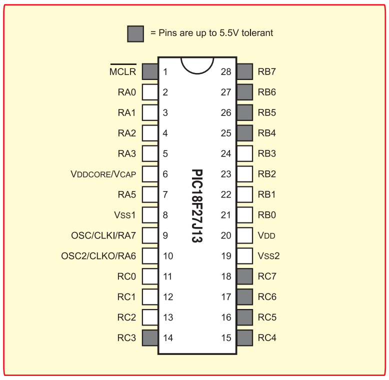


Fig.1. Processor pinout

One of the main attractions of this processor is its unusual power supply requirements – unlike most that require 5.0V or 3.3V regulated to within 5%, this processor will operate across 2.15V to 3.6V, making it ideal for battery operation from two AA cells. With a factory calibrated internal oscillator, only a few capacitors and a resistor are required to get a working system, and as the processor is just £3, the total circuit costs are minimal. The basic circuit that we will start with this month is shown in Fig.2.

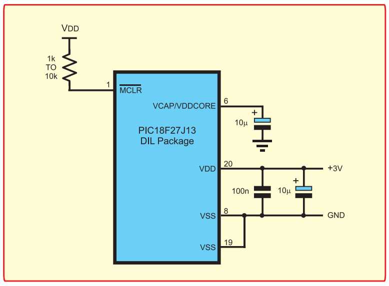


Fig.2. Minimal circuit

Naturally, whether you *can* run off an unregulated battery pack will depend on what other components are in your project. LEDs, buzzers and switches will work fine across such a range; a GPS receive may not, and will require that the overall circuit power supply be regulated to 3.3V. For simple circuits however it's a nice feature that can significantly reduce the cost and complexity of the design. For a learning activity it's ideal.

The minimum component count for a working processor consists of a 1kΩ to 10kΩ resistor on the MCLR pin to ensure a clean power-on reset, two decoupling capacitors on the power supply rails and a 10µF capacitor on the Vcap pin. The Vcap pin connects to the internal 2.5V regulator which powers the core of the processor.

Heartbeat

As with all microprocessor systems, an oscillator is required to provide the heartbeat that moves the processor's instruction decoding along (exactly analogous to the pendulum in a clock, or the cranking handle on the Baggage Difference Engine.) This is normally satisfied by the addition of a crystal or ceramic resonator to provide a very precise timing reference. The PIC18F supports this, but it also contains an on-chip oscillator based around a calibrated internal resistor and capacitor, saving the cost and board space of the extra components.

This type of oscillator is not as precise and stable as a crystal as the frequency of operation is dependant on the supply voltage and temperature, even after factory calibration. Timing critical operations such as RS232 communication may not be possible with an unregulated supply, but as the variation in speed is no worse than about 10%, it's perfectly suited for sounding buzzers, flashing LEDs and communicating with devices using interfaces such as SPI or I2C.

Construction

When working with a new processor it's advisable to avoid diving in with the soldering iron and committing ideas to circuit board; we like to start off with a re-usable breadboard (see Fig.3). It took just a few minutes to wire up the circuit shown in Fig.2. Although it's not a practical assembly technique for a completed project it is a great way of testing out ideas, and over the years we have complimented our box of breadboard hook-up wires with various add-on interfaces such as regulated power supplies, RS-232 adaptors and even Ethernet interfaces.

This basic assembly will allow us to get past the initial hurdles on a new processor – how to set the configuration bits correctly for example – and to explore one of the more frequent questions: 'What's the difference between absolute and relocatable program development, and which should I use?'

Memory layout

First, let's get a better understanding of the memory organisation in this particular processor, as shown in Fig.4. There are three distinct regions:

The 'Stack', which is a small, 31 word area of RAM that is used by the

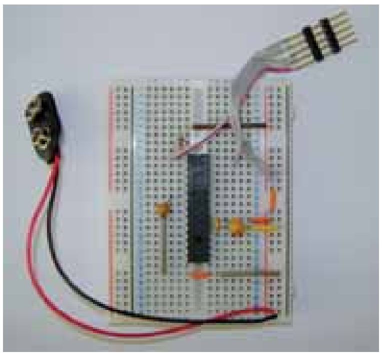


Fig.3. Breadboard layout

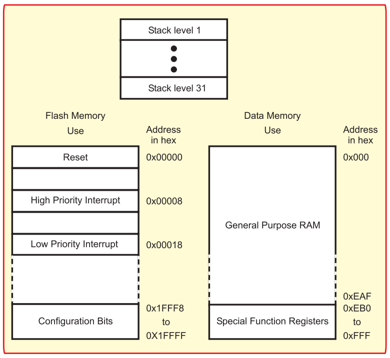


Fig.4. Processor memory layout

processor to remember the return address when you make a subroutine call in your code. Each RAM location stores a single address; therefore, you can make up to 31 nested calls. 'Nesting' is when a routine, say func1, calls routine func2 (that's 1 level of nesting.) If func2 then calls func3, that's a 2nd level of nesting, as the processor must remember the return address in func2 *and* the subsequent return address into func1. Clearly, making 31 nested calls is a very unlikely scenario in assembly langugage programs, so its limited size is not an issue. This memory is controlled by the processor directly, and is effectively invisible to the user. So, in other words, we can ignore it.

The 'Data Memory' is the area of user accessible special function registers and user registers, the latter being used for all your application variables. On this PIC we have 3760 bytes available for use; a large amount for most hobbyist projects.

The special function registers are a form of RAM – whatever you write to them will be lost when you remove power – but they are connected to the internal peripherals of the processor, and control how those peripherals operate. It's important to understand the layout of the memory and at what addresses the user data starts and stops, because in some cases you will need to explicitly state what addresses your variables will be located at. More on this later.

Flash memory

The final memory area is the 'Flash' memory. At 128K bytes (that's 128 × 1024 bytes, not 128 × 1000) this is quite large by microcontroller standards and you would find it difficult to fill it all with a hand written assembly language program (although the memory can be put to other uses too, such as text strings or data.) Unlike RAM this type of memory retains its contents when power is removed, which is why it is used for storing the program code.

As can be seen in Fig.4, the Flash memory has some locations that are reserved for special purposes. The very last eight locations hold the processor's configuration bits, which are specified by the user in their program source code (we will talk about configuration bits in a moment.) The locations 0, 8 and 24 (0×18 in hexadecimal) are the fixed addresses for power-on start address, high-priority interrupt and low-priority interrupt respectively.

If your program does not use interrupts then you are free to use locations 8 and 24 as you wish. Location 0, however, must always be where your program starts from; if you specify the start address as somewhere else, then on power-up the processor will start executing un-programmed locations which will have unexpected results. It won't damage your processor, but your circuit will not function.

By now you may have noticed an oddity – both the Data and Flash memory have addresses that start from 0. They appear to overlap! This is not an error – the two memory regions are physically isolated from each other. When you specify an address within an assembly instruction, the region of memory to be accessed is implied by the instruction code. So for example, if you write the instruction **bra 100** the processor knows that '100' refers to Flash memory location 100, not data memory location 100. A little confusing, but this memory layout – referred to as 'Harvard Architecture' – enables the processor to be more efficient and execute instructions quickly.

In the past, one of the downsides of the PIC design was the grouping of data and special function registers (SFRs) into 256 byte 'banks'. To access a variable or SFR you had to first select the bank in which it sits by writing to the bank select register BSR. This complicated the design of the program by forcing you to think carefully about how to group variables together into banks. If you didn't do this, your code quickly grew to contain a seemingly random sprinkle of bank select writes, bloating and slowing down your code.

The PIC18 family of processors improved (slightly) on this by adding a new 'mode' in which an instruction can operate – **Access Bank**. In this mode the data memory is organised as 256 locations, the first part being for data and the remaining being the SPRs. On the plus side you no longer need to think about which bank you are addressing; on the negative side, you can only access 96 data bytes. For many programs this is not a problem, and you still have access to the rest of the data memory using the normal access mode if you wish.

Oscillator

Before we power up the circuit we need to consider the oscillator setup. The PIC has a variety of configuration options (internal, external, low power, phase-locked loop multiplied) and we have to choose, for this particular circuit, what option is best. Section 3 of the datasheet explains these in full (if somewhat confusing) detail.

We've already decided to simplify the external component count and use the internal 8MHz oscillator (INTOSC in Microchip-speak) but there are a few more options to consider. Do we want to output the clock signal on one of the port pins? No, we have no need for that – so we want INTOSC rather than INTOSCO. Do we want to use the phase-locked loop to multiply the 8MHz signal up to 96MHz? It's tempting, but the processor will only operate down to 2.15V with an 8MHz clock frequency (there's always a catch – and this point can only be found by looking at figure 30-1 at the end of the datasheet.) So we will keep with 8MHz, which means we need to select the INTOSC configuration bits. So how do we set this?

Configuration Bits

We've mentioned that some of the data memory of the processor is used for Special Function registers, to control the operation of the various hardware peripherals on the processor. These are setup by the user application once the processor has powered up and started running your program. The Configuration Bits area of flash memory is used to configure certain hardware features of the processor that determine how the processor operates *before* it starts up – and that is why these particular registers must be stored in Flash memory, so they can be accessed automatically by the processor before your program has started running.

There are eight memory locations containing these configuration bits, a total of 25 different functions that must be properly configured *before* your code can run. There is no way around this: you must understand what these configuration bits do. These bits are explained in section 27.1 of the datasheet, and a summary is shown in Fig.5.

Fortunately, the majority of these bits control advanced features that we can ignore, and the default settings are acceptable. There are a few essentials that must be changed from the default. These are:

XINST Extended instruction set enabled. This option selects an enhanced assembly language instruction set designed for use by the 'C' language compiler. As we are writing assembly language programs by hand, we will disable this option and use the normal instruction set.

WDTEN Controls the watchdog timer. This is an internal processor timer that will cause the processor to reset unless a special sequence of instructions are periodically executed. Although this feature is great for recovering a program that has become confused, it is un-necessary for most hobbyist programs and will get in the way during initial program development. We will disable it.

IESO Two-Speed start-up. Allows the processor to start (quickly) on the internal oscillator, and then switch to an external crystal oscillator later. We are not using an external oscillator, so we must disable this feature.

FCMEN Fail-safe clock monitor. This feature checks that the external oscillator is running, and switches to an internal oscillator if it does fail. We are not using an external oscillator, so we must disable this feature.

FOSC These bits determine what oscillator configuration we will be using, as just mentioned. We need to change this to INTOSC.

Filename		Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0	Default/ Unprog.Value
300000h	CONFIG1L	DEBUG	XINST	STVREN	CFGPLLEN	PLLDIV2	PLLDIV1	PLLDIV0	WDTEN	1111 1111
300001h	CONFIG1H						CP0			1111 -1- -
300002h	CONFIG2L	IESO	FCMEN	CLKOEC	SOSCSEL1	SOSCSEL0	FOSC2	FOSC1	FOSC0	1111 1111
300003h	CONFIG2H					WDTPS3	WDTPS2	WDTPS1	WDTPS0	1111 1111
300004h	CONFIG3L	DSWDTPS3	DSWDTPS2	DSWDTPS1	DSWDTPS0	DSWDTEN	DSBOREN	RTCOSC	DSWDTOSC	1111 1111
300005h	CONFIG3H					MSSPMSK	PLLSEL	ADCSEL	IOL1WAY	1111 1111
300006h	CONFIG4L	WPCFG	WPFP6	WPFP5	WPFP4	WPFP3	WPFP2	WPFP1	WPFP0	1111 1111
300007h	CONFIG4H							WPEND	WPDIS	1111 - -11
3FFFFEh	DEVID1	DEV2	DEV1	DEV0	REV4	REV3	REV2	REV1	REV0	xx1x xxxx
3FFFFFh	DEVID2	DEV10	DEV9	DEV8	DEV7	DEV6	DEV5	DEV4	DEV3	0101 10x1

Fig.5. Configuration bits

DSWDTEN This is a very slow timer clocked from an on-chip oscillator that can wake the microcontroller from a 'deep sleep' condition where the processor is almost completely powered down. This is an advanced feature of the chip that we will not be using, so we should disable it.

Phew! That's some heavy stuff to deal with when starting out with a new processor, and those bits are only a fifth of the complete set. For more complex designs it's likely that some of those other bits will need to be looked at, but for now with those changes indicated above, the processor should be able to boot the internal oscillator and run at a speed of 8MHz. And how do we make these bits change? We will explain that next month. First, we look at how to develop the software.

Software development

There are two aspects to software development for microcontrollers: The software used to translate the source code you write into a program file, and the hardware required to transfer that program file to the Flash within the processor. Microchip have made the design of the hardware interface open so there are many third party devices on the market, but we have stuck with Microchips's PicKit3 device because it is small, cheap and easy to use. While an outlay of £20 to £40 pounds may appear excessive, it's a long term investment and *significantly* cheaper than what we used to pay 20 years ago!

The software development tools are, thankfully, free. Microchip's MPLAB (running to over 110MB now) contains an editor, assembler and simulator built into a single application called an integrated development environment or IDE. Two versions of this are available, MPLAB v8, supported on Windows and the newer MPLAB-X which runs on Windows, Mac OS and Linux. MPLAB-X is an improvement on the older MPLAB but does have a steep learning curve, so we will stick with MPLAB. Microchip continue to develop this tool, and at the time of writing it is at version 8.86. It's available for download from the Microchip website as a zip file.

Installing MPLAB

Extract the contents of the zip file to your desktop, which will result in five files appearing. Double-click on the setup.exe file to start installation. You will be presented with a series of dialogs prompting you with various options; simply click 'Next' to these as the default settings are well chosen. Installation will take a few tens of seconds; at the end you will be prompted to click 'Finish'. On doing so you will be shown a dialog displaying a list of various help files; close this by clicking the 'X' button in the top right corner. You can return to these at any time by clicking on the 'Help' menu option within MPLAB. You can now delete the five files extracted to the Desktop.

We've already covered MPLAB in an earlier tutorial series so we will assume a basic familiarity with MPLAB; instead we will be concentrating on relocatable verses absolute development.

Absolute assembly

So let's finally get to the point of this month's article: what is 'Absolute' program code, and is it a good thing?

To illustrate the point we will use a very simple program which will change the pins of PORTB to outputs, and set the even numbered pins to a low voltage level and the odd numbered pins to a high level. We won't be loading this program onto the processor, just inspecting some of the files created.

```
    include <P18f27J13.INC>
        org 0
        movlw   0
        movwf   TRISB
        movlw   0x55
        movwf   LATB
loop:
        goto    loop
        end
```

To enter this program in MPLAB click on 'Project' followed by 'Project Wizard', click 'Next', select our device PIC18F27J13, click 'Next', select the MPASM Toolsuite from the top dropdown list and click 'Next'.

We now have to create a project file to hold all our settings. Browse to a directory where you would like to store this test program and enter the filename as **test1**. Click 'Save', 'Next', 'Next', 'Finish'. That creates the project file; to type our program in create a new source file by selecting 'File' and then 'New'. A blank window will appear.

Type the program list above into the window, taking care to use the same capitalisation and indentation. Once entered select 'File' followed by 'Save'. Type the file name as **test1.asm** and click the 'Add File To Project' checkbox at the bottom of the dialog.

You can now build the program by selecting 'Project' followed by 'Build All'. You are immediately prompted whether you wish to build as 'Absolute or Relocatable' – choose Absolute. A warning message will appear; ignore this and click 'OK'.

The program has now been created. If you open Windows Explorer and navigate to the project directory you will find a number of files have been created. The one of interest to us at the moment is the listing file (with a .lst file extension) for our assembly source code. This text file lists the translation of the source code we entered into the machine code values that are interpreted by the processor. If you open this file in an editor and scroll down to the 'goto loop' line, you will see how the assembler has translated this text on the lefthand side. It should show the following:

```
000008 EF04 F000
```

If you look up the 'goto' instruction in the processor datasheet on page 435 you will see that the assembler has inserted the correct address – 00004 (the 16 bit word address of the loop label.) The assembler knows at what address the loop label is, as we fixed the starting address of this program with the 'org' statement.

Next Month

That's all we have space for this month so in the next installment we will repeat this exercise with relocatable assembly and discuss the differences, and explain a tool that as a consequence becomes essential for building programs – the linker. We will also modify the program to use a timer peripheral and interrupts to demonstrate the benefits of these techniques, and explain how to avoid the inevitable 'gotcha's' associated with them.

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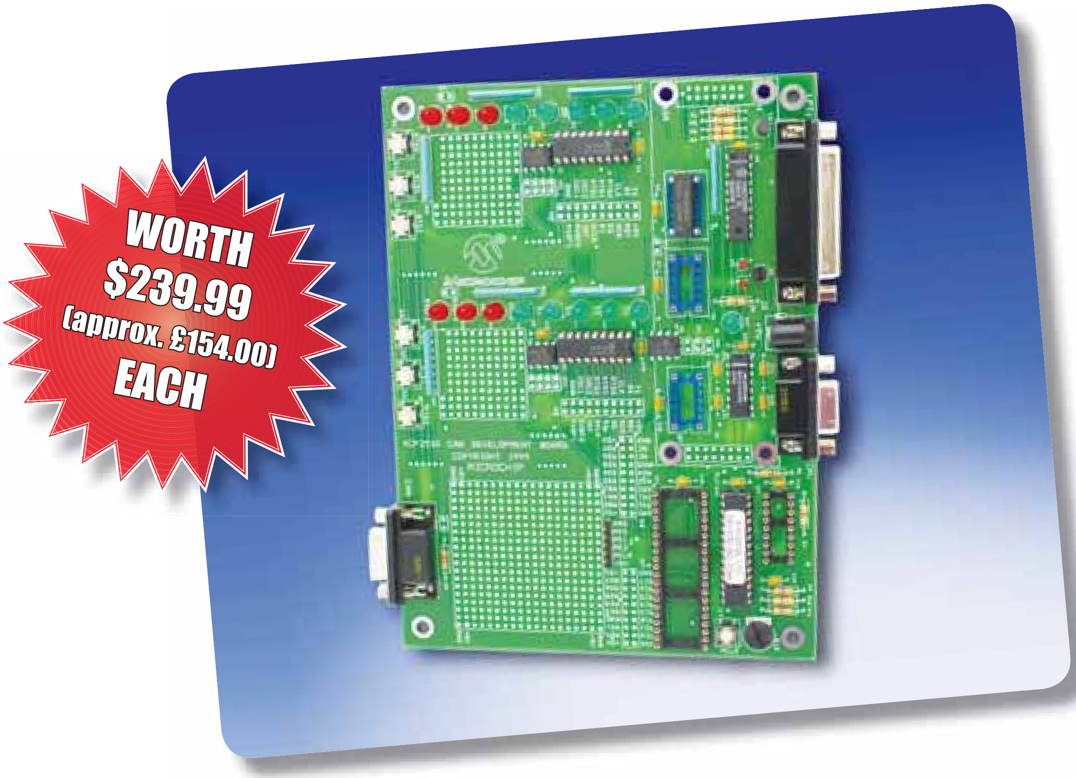

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Real ADCs

THIS month we consider a question about analogue-to-digital converter (ADC) specifications posted on *EPE's Chat Zone* by **echase**.

How much IC-to-IC error is there on the A/D's on 8-bit PICs? I need the error to be within 1 LSB at the midpoint of a 10-bit sample; ie, with a voltage derived from the midpoint of the supply rail, one PIC reads 512 because I have a trimpot calibrated to the middle of the 512 step. If I change the PIC, will the new one always still read 512 without me having to adjust the trimpot? Based on a sample of only two, I got them both to read the same.

For one PIC, the datasheet quotes integral error, differential error, offset error and gain error all at ±1-bit. Added together, that is four-bits of error, but in reality I guess you don't get them all worst case. To get my required accuracy I guess I really need ±½ bit.

ADCs are key components in many electronic systems. They provide the means of getting the analogue information from the real world – including signals from a wide range of sensors, from temperature to video – into a form which can be processed by software and sent over digital communication channels. Many projects published in *EPE* include ADCs, often, as described by echase, those included in PIC microcontrollers. This month, we will take a look at ADC specifications and the errors associated with data conversion to which echase refers in his question.

Key to ADCs

The ADCs built into PICs and other microcontrollers are very useful and help keep component counts low, but sometimes they do not have the required capabilities. In such cases there are a large number of alternative converters available from a variety of manufacturers. These external ADCs are typically connected to the microcontroller via a standard serial bus, such as SPI or I²C.

The need to sometimes use external ADCs does not imply that those provided on microcontrollers are poor – they represent a good compromise between various performance trade-offs in areas such as speed and resolution (number of bits). Higher performance typically implies increased cost and complexity, which is not justifiable in a general purpose microcontroller where not every user will need a high performance ADC, or need highest performance in same specification.

Speed and number of bits is a key trade-off in ADCs. For example, Analog Devices, (**www.analog.com**), who are probably the world's leading manufacturer of data converters, currently provide ADCs ranging from 6-bits up to 24-bits. These have speeds, which is referred to in terms of throughput in samples (conversions) per second (SPS), ranging from less than 1000 samples per second (1KSPS) to over 250 mega-samples a second (MSPS).

The more bits an ADC converts to, the more difficult it is to achieve high speed. Using Analog Devices' online High-Speed ADC Finder, we find, at the time of writing, the fastest speed category is 250+ MSPS and the highest resolution is >/=16 bits. Just one converter fits this combined high specification, the 16-Bit, 250MSPS AD9467, which costs around $100 in bulk quantities. Dropping to fewer bits; at the same high speed, there are a few devices, including the 8-Bit AD9481. 500 MSPS are also available at this resolution.

For high precision, slower speeds are required. Using Analog Devices' Precision and General Purpose ADC Finder, we find the 2.5MSPS, 24-Bit AD7760 as the fastest 24-bit device. This costs around $25 in bulk.

Signal conversion

When an analogue signal is converted for digital processing by an ADC, the resulting digital representation has a finite number of possible value (codes), rather than the effectively infinite number of possible analogue voltages (or currents). This is illustrated in Fig.1 which shows the input-output relationship for three data converters. In all cases the input is an analogue voltage and the output is a digital code.

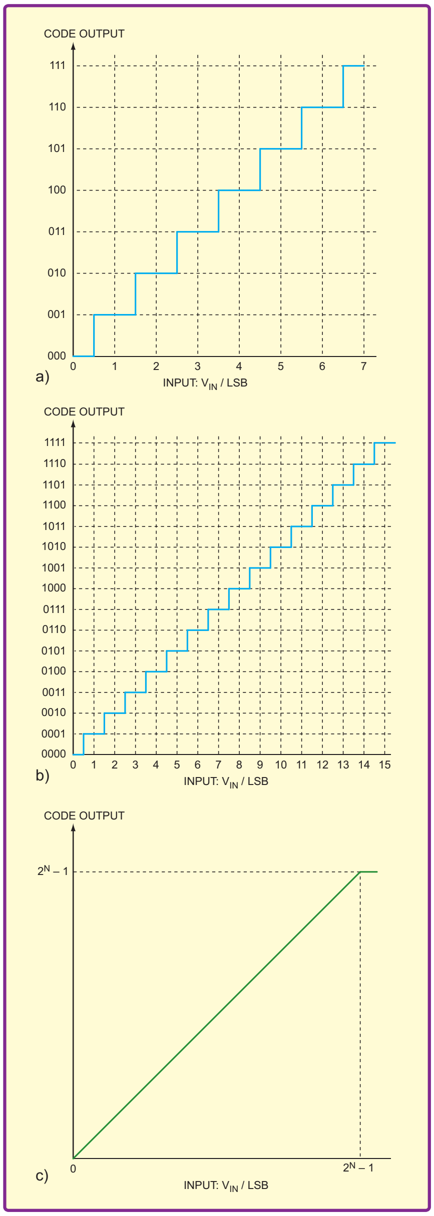


Fig.1. Input-output (transfer) function for ADCs (a) 3-bit ADC (8 output codes), (b) 4-bit ADC (16 output codes), (c) ADC with an infinite number of bits, N – this is the ideal 'straight line' transfer function.

An ADC transfer characteristic has a staircase shape. The more bits in the output code, the more steps we get in the complete transfer characteristic, as can be seen by comparing the 3-bit and 4-bit characteristics in Fig.1(a) and Fig.1(b). If we had an infinite number of bits in the output code, the transfer characteristic would be a perfect straight line, as seen in Fig.1(c).

The range of analogue input voltages over which an ADC performs conversion is set by two reference voltages in the ADC circuit – low reference voltage (V_{RefL}) and the high reference voltage (V_{RefH}). In some cases, these may be controlled by the user, in others they are fixed in the ADC chip. One reference point can be ground, but it does not have to be. For consistent conversion these reference voltages must be accurately set and maintained.

An *N*-bit ADC converts analogue input data into 2^N codes. The voltage difference between adjacent codes is called the least significant bit (LSB). LSB is given by

$$LSB = \frac{(V_{RefH} - V_{RefL})}{2^N}.$$

For example, if a 12-bit ADC has $V_{RefL} = 0$ and $V_{RefH} = 5V$ the LSB is;

$$LSB = \frac{5}{2^{12}} = \frac{5}{4096} = 1.22mV .$$

If an *N*-bit ADC's input range is defined as $V_{RefH} - V_{RefL}$ then the largest output code represents a fraction $(N\text{-}1)/N$ of this range. For example, for a 3-bit converter this is 7/8^{ths} of the range. This is shown in Fig.2, for which $2^N = 8$, V_{RefL} is 0 and the maximum code step is centred on 7 on the input axis.

Quantisation error

Due to the finite number of codes, the voltage represented by the ADC's code after conversion will not generally be exactly equal to the original input voltage. The difference is known as the *quantisation error*. This error has a maximum value of $\pm\frac{1}{2}LSB$ with the transfer functions illustrated here. The variation of error with input voltage for a 3-bit ADC is shown in Fig.2.

Quantisation error is not the result of non-ideal circuit components; it is a fundamental property of the conversion process. An ideal 3-bit ADC produces the quantisation errors shown in Fig.2. Real ADCs will produce additional errors, which we will discuss shortly.

If an ideal ADC is used to measure the same fixed voltage in a noise-free circuit, the same quantisation error will occur each time. However, if an ADC is used to sample a continuous signal (eg, audio) then the quantisation errors will be different on each conversion and over time they will have the same statistical properties as random errors. Thus, quantisation adds noise to a digital representation of a signal which was not present in the original analogue input. For *N*-bit quantisation, the signal-to-noise ratio (SNR) is given by

$$SNR = 6.02 \times N + 1.76 \text{ dB}$$

Adding an extra 1-bit of resolution provides about 6dB improvement in the SNR. Again, this is for an ideal converter; real converters will add additional noise.

Thinking about the size of an LSB is useful when designing a system containing ADCs. The resolution used should be commensurate with the accuracy and SNR required in the system. Too low, and the ADC may be the weakest link, but if it is much higher than necessary you may be wasting your money. Table 1 helps provide an idea of the size of 1 LSB expressed in various ways – as a percentage or parts per million of full input range, as value in decibels relative to the range and as a voltage for an ADC with a 5V range.

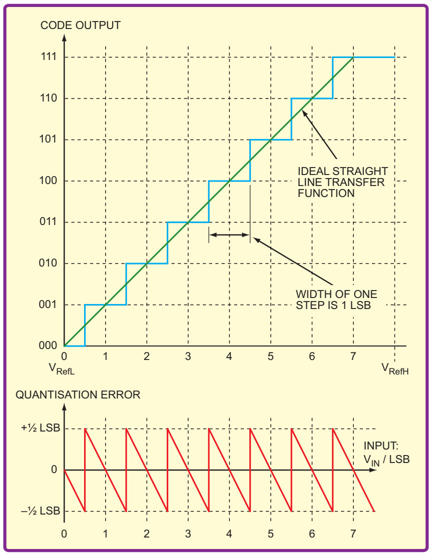


Fig.2. Comparison between the ideal straight line transfer function and the actual transfer function of a perfect 3-bit ADC. The difference is the quantisation error.

In error

So far, we have only considered ideal ADCs. Real devices are subject to a number of additional errors, some of which are mentioned by echase. These are: offset error, zero scale error, full scale error, gain error, differential non-linearity (DNL) and integral non-linearity (INL).

Table 1 – The size of one LSB for ADCs with various numbers of bits (ppm is parts per million).

Number of bits	Relative size of LSB	LSB in dB	LSB voltage for 5V input range
3	12.5%	-18	625mV
4	6.25%	-24	313mV
8	0.39%	-48	19.5mV
10	977ppm	-60	4.88 mV
12	244ppm	-72	1.22mV
16	14ppm	-96	76.3μV
22	0.24ppm	-132	1.19μV

Zero scale error is the difference between the actual and ideal transition voltage to the first code, as shown in Fig.3, where the error is about +1.75 LSB. The error is usually expressed in terms of LSBs rather than absolute voltage values, as this is better for making comparisons between ADCs.

ADCs may have a constant DC offset error – a fixed DC error across the entire conversion range. If there are no other sources of error then the offset error and zero scale error will be the same (as in Fig.3). In general, other errors (specifically nonlinearities) will be small at the first code transition, so zero scale error should provide a good estimate of the offset, but this is not absolutely guaranteed.

In Fig.2 we saw a comparison between the ideal straight line transfer function and the actual staircase-shaped function of a perfect ADC with a limited number of bits. We can draw an idealised line like this – which joins up the code transition points – through a real ADC transfer function, even if the ADC is not perfect. Fig.4 shows an ADC in which the slope of this ideal line is different from what it should be; that is, the ADC has a gain error. An effect of gain error is that the input voltage at which the transition to the largest output code occurs will be wrong, as shown in Fig.4

The full scale error of an ADC is the difference between the actual and ideal final code transition voltage. Like zero scale error, this is usually expressed in terms of LSBs. The ADC transfer function in Fig.4 only has full scale error, but a real device may have a zero scale error as well. If the ADC had no

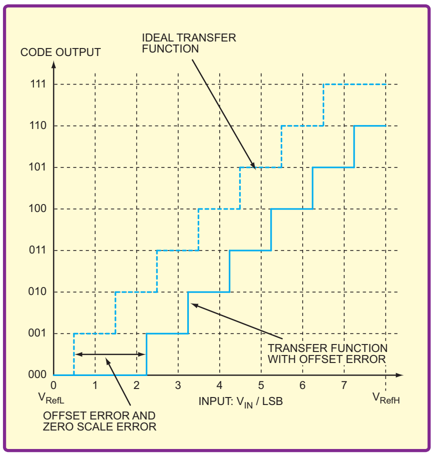


Fig.3. ADC zero scale and offset errors

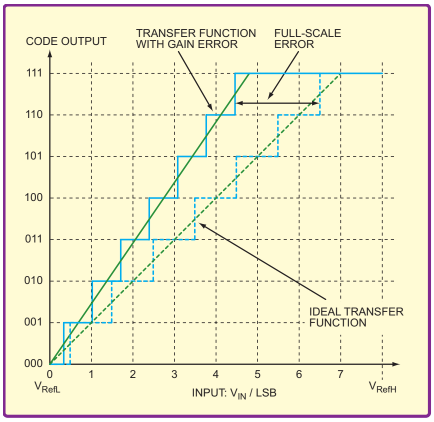


Fig.4. ADC full scale and gain errors

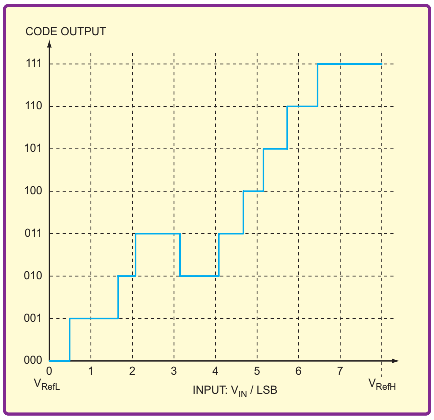


Fig.6. Non-monotonic ADC transfer function

nonlinearities and no zero scale error, or if the offset is removed by shifting the transfer function accordingly, the resulting full scale error will be related, only the error in gain (slope of the ideal transfer function). Thus gain error for an ADC can defined as:

Gain error = full scale error – zero scale error

Like offset error, this definition may be problematic if the ADC has significant nonlinearities around the final transition voltage.

The errors we have considered so far (offset and full scale) do not cause any deviation from a 'staircase' which could be represented by an ideal straight line. In general, real ADCs do not have such perfectly straight transfer functions. Errors which cause deviations from this are called nonlinearities, which we have already mentioned as they may complicate the definition of other errors. Before looking at nonlinearities in general we will define a couple of special cases, which represent relatively large anomalies in the transfer function.

Missing code

Fig. 5 shows an ADC transfer function with a missing code. A missing code means that the ADC never outputs some digital code values, whatever input is applied. This looks very dramatic in Fig.5, but would seem less so with more bits. If your design uses an ADC with a few more bits than you really need, missing codes will probably not be a problem. ADCs may be guaranteed to have no missing codes – this will usually be stated on the datasheet.

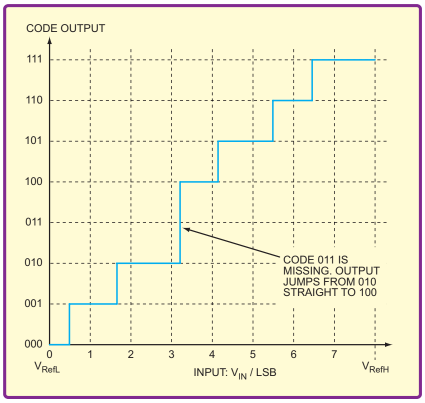


Fig.5. ADC transfer function with a missing code

Ideally, increasing the input voltage to an ADC will either not change the output code, or produce a higher code value. If increasing the input voltage produces a lower code value at any point over the ADC's input range, the converter is said to be non-monotonic. This is illustrated in Fig.6. ADC datasheets will usually state if a device is guaranteed to be monotonic. Monotonicity is particularly important if the ADC is part of a feedback loop, as non-monotonicity can lead to instability of the loop (oscillations).

Linearities

Two key parameters for characterising the quality of ADCs transfer functions are differential non-linearity (DNL) and integral non-linearity (INL). DNL measures the difference between the ideal and actual code widths. The code width is the range of voltage for which a particular code is output by the ADC – it is the width of each step in the staircase transfer function.

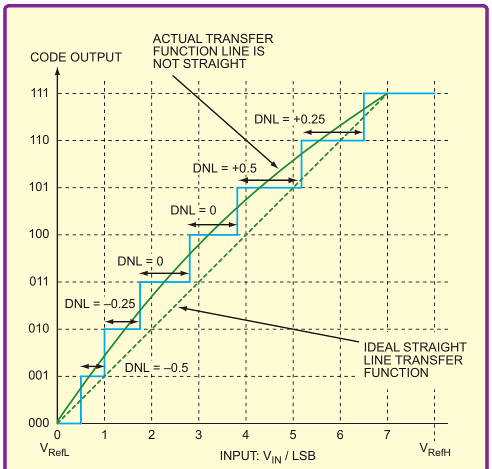
Ideally the code width is 1 LSB, which corresponds with a DNL of 0. Other code widths have non-zero DNLs, for example, if the code width is 1½ LSB the DNL is +0.5. This is illustrated in Fig.7, which shows an ADC transfer function with significant non-linearity. INL measures the accumulation of error as one moves through the converter's codes (the sum of INL's from the first code to the current code). A missing code has a DNL of –1.0.

The transfer function in Fig.7 does not have any zero scale or full scale errors – these are corrected before DNL and INL are calculated.

For a real ADC, the maximum positive and negative DNL and INL values may be given on the datasheet. For more than a few bits it is not practical to list all values (as in Fig.7), but graphs of DNL and INL against digital code may be provided by the manufacturer. These graphs provide insight into the quality of the converter.

Adding offset, gain error, and INL does give some idea of maximum deviation from ideal characteristics, often referred to as absolute error. Both INL and DNL are not included, so the total is not as bad as echase suggests. Absolute error is less important than linearity in many applications, but may be significantly worse than the linearity.

However, this assumes that no calibration has been performed. In applications where absolute ADC accuracy is important it is usual to include some form of calibration process (eg, in software) and possibly temperature compensation. The voltage references used by the ADC will not typically tend to influence linearity much, but may have a significant effect on absolute accuracy without calibration. The ADCs in some PIC families provide a self-calibration process, which compensates for offsets – this might be of some benefit to echase.



BIT	DNL IN LSB	INL IN LSB
1	–0.5	–0.5
2	–0.25	–0.75
3	0	–0.75
4	0	–0.75
5	+0.5	–0.25
6	+0.25	0

Fig.7. Nonlinear ADC transfer function showing DNL and INL values

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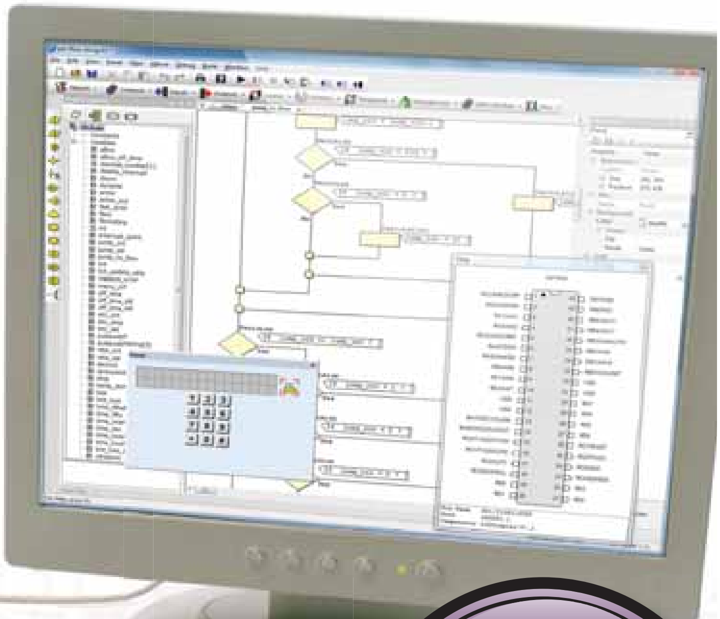

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PICmicro TUTORIALS AND PROGRAMMING

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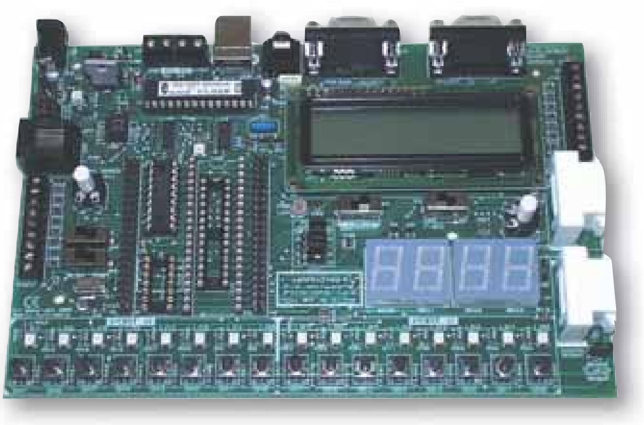

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SOFTWARE

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(Formerly PICtutor)

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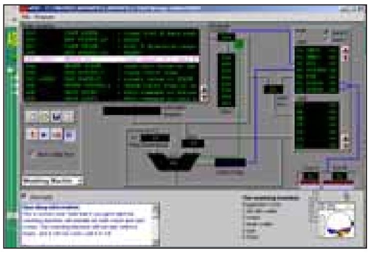

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FLOWCODE FOR PICmicro V5 (see opposite page)

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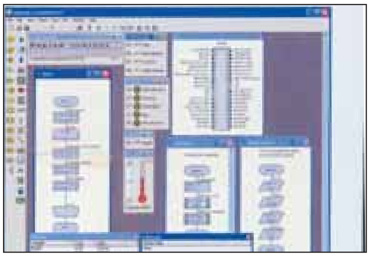

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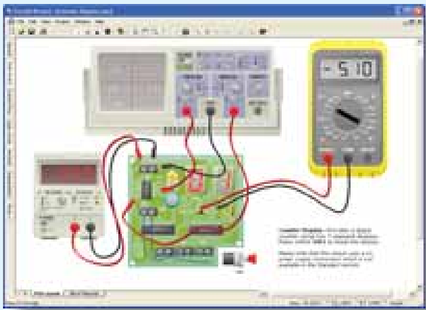

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Alternative to PCBs...

THESE days, it is the norm for electronic devices, whether commercially produced or home constructed, to be based on a custom printed circuit board. If you take a look at a few *EPE* project articles you will probably not find many that are based on any other method of construction.

Although the impression given is that there are no alternatives, this is not the case. Admittedly, most of the alternatives are primarily aimed at the production of prototype units, but many are perfectly acceptable for small production runs or home constructed gadgets.

Got it wrapped

Wire wrapping and variations on this basic scheme of things are popular with professional users, but are perhaps less so with hobbyists. One possible reason for this is that this general type of construction can be quite expensive, even though it is really a very basic approach to things. Any wire wrapping technique requires the integrated circuits to be fitted in special holders that have pins that are longer and often more elaborate than the normal type. Individual pins can also be fitted to the board, so that components such as resistors and capacitors can be accommodated, but this type of construction is mainly used with digital circuits where the components are predominantly integrated circuits.

The board itself typically has numerous holes on a 2.54mm (0.1-inch) matrix, with pads so that the pins can be soldered in place, but no tracks connecting the pads (Fig.1). There is a possible exception here, with a couple of rows connected by tracks and used as power rails. Instead of using tracks for interconnections, lengths of thin insulated wire are used. The connecting wires run straight from one connection point to another, and they are cut slightly longer than the distance between these two points. Several millimetres of insulation are removed from the end of a connecting wire, the bare ends are wrapped around the pins at the connection points, and then they are soldered to the pins. With this method, it is inevitable that there will be numerous wires crossing over one another, but the insulation prevents any short-circuits.

One variation on this basic technique is to have the wire covered in a special insulation that makes it possible to solder the wires in place without having to remove any of the insulation first. You simply wrap the wires in place and solder them to the pins in the normal way. The unwanted pieces of insulation are burned away during the soldering process. With this system, it is easy to join several pins together because a single piece of wire can be taken from one connection point to the next, joining any required number of points.

I am not sure if any are still currently available, but there have certainly been solderless versions of wire wrapping. There are some special tools available that make wire wrapping quicker and easier. The most important of these is a pen-like tool that dispenses the special wire instead of ink. This tool can include a facility for stripping the insulation. Some systems include so-called 'combs' that enable the wires to be laid horizontally and vertically rather than simply going straight from one point to another at any angle. This gives something that is more like a conventional printed circuit board and usually looks neater, but is not necessarily any better.

An advantage of the various wire wrapping systems is that they do not require the user to have much in the way of design experience or ability. Converting a circuit diagram into a working unit is basically just a matter of fitting the components on to the circuit board in any semi-sensible position, and then adding the connections one by one until they have all been completed. Unlike designing

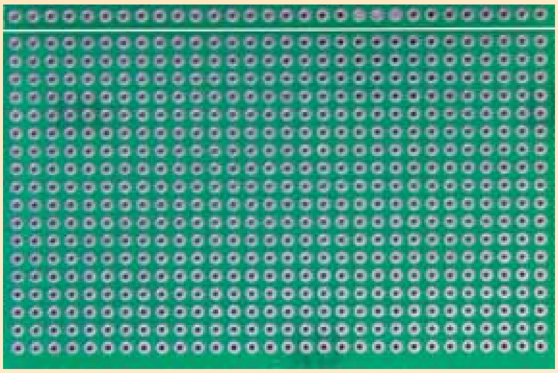

Fig.1. Boards for use with wire wrapping systems usually have pads, but no tracks. Pins are soldered to the pads in order to fix them to the board, and insulated wires are then used to carry the interconnections

a printed circuit board, there is no need to worry about carefully routing the tracks to avoid short-circuits. As pointed out previously, the insulation on the wires enables them to crisscross here there and everywhere without producing any problems.

The main drawback is probably that these systems can be relatively expensive. The special integrated circuit holders can cost pounds each, whereas an ordinary holder costs a matter of pence. It can also be difficult to find and rectify any mistakes that are made. Wire-wrapping usually works well with digital circuits, but the crisscrossing of wires can give problems with analogue circuits.

Because there are several systems that differ in points of detail, it is important to study the manufacturer's literature for any system before buying it. Make sure that you know exactly how it is used, and that it suits your requirements. Tools and materials for one system will not necessarily be usable or work well with a different system, so it is probably best to avoid a 'mix and match' approach. Select a manufacturer and then stick with the products associated with their system.

Plain truths

Perhaps the most basic of construction methods is the one that is based on a plain matrix board and uses the component leads to carry the interconnections. Pieces of tinned copper wire can be used to provide extensions when the component leads are inadequate. A plain matrix board has a matrix of holes, but there are no copper pads or tracks.

This method of construction gives a sort of pseudo printed circuit board with wires rather than copper tracks to carry the connections. However, unlike wire wrapping there is no insulation on the wires, and they must be routed across the board in a fashion that avoids short-circuits.

It is actually possible to have one wire cross over another without producing short circuits, and one way of doing this is to take one of the wires through a hole and on to the top (component) side of the board. It is then taken over the other wire, and then back to the underside of the board via another hole. This gives a sort of pseudo double-sided printed circuit board. The simpler alternative is to simply add some PVC sleeving on one of the wires where it crosses the other wire.

An obvious problem with this method of construction is that the wires carrying the connections are not glued to the board like the copper tracks on a printed circuit board. There are no copper pads to help anchor everything in place either. A finished board of this type should still be quite strong and reliable though. This method of construction works well with most analogue circuits, including high frequency types, but is not usually a practical proposition with digital projects.

Probably the main problem with it these days is that many modern discrete components have short leads or pins. This makes it necessary to resort to numerous pieces of wire to fill in the gaps left by inadequate leadout wires. The layouts must be designed very carefully so that the problem of having to insulate excessive numbers of crossed wires is avoided. Sensible positioning of the components is essential.

On track

Stripboard is the most popular alternative to custom printed circuit boards for electronic hobbyists. It provides a universal rather than a custom printed circuit board, and like most good ideas it is very simple. On one side it looks the same as a plain matrix board, but on the other side there are copper strips running along each row of holes (Fig.2). Stripboard is used in essentially the same way as a custom printed circuit board. The components are mounted on the plain side of the board with the leadout wires threaded through the holes. The leads are cut to length on the underside of the board, and then soldered to the copper strips. Components with pins are fitted and soldered to the board in the normal way.

On the face of it, stripboard could never work in practice because each copper strip can only carry one set of connections. In practice, some of the copper strips are cut in several places so that each section can carry a different set of connections. There is actually a special tool available for making the cuts in the strips, but a twist drill bit of around 5mm in diameter does the job well enough.

Either way, it is essential that the cuts are deep enough to properly sever the strips across their full width, but they must not be so deep that they seriously weaken the board. Using something like a modelling knife to make the cuts is a bit risky and is best avoided.

Ups and downs

Another potential limitation of stripboard is that the tracks all run in the same direction and can only carry connections across the board. The way around this is to use link wires on the component side of the board to carry connections up the board. Numerous link wires are a common feature of stripboard layouts.

Using stripboard it is possible to produce neat finished projects, but inevitably with a universal product such as this, there are a few problems. It can be used successfully with digital and analogue circuits, but digital types often require huge numbers of link wires. The capacitance between the copper strips is quite small, but it still precludes the use of stripboard in many high frequency applications. The small

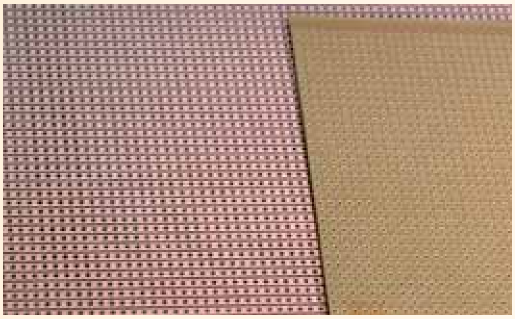

Fig.2. Normal stripboard has copper strips on one side of the board, but the other side is plain. As with a custom printed circuit board, components are mounted on the plain side of the board

amount of capacitance tends to couple signals from one strip to another.

Stripboard is nothing like as strong as a typical custom printed circuit board. This is not surprising when you take into account that a fair percentage of each board consists of empty holes. The material used for some boards seems to be quite brittle. Finished boards should still be tough enough, but it means that a 'kid glove' approach must be taken when drilling and cutting stripboard.

Boards are available in several standard sizes, and with practically every circuit it is necessary to cut a standard board down to the required size. There are quick ways of trimming stripboard, such as using cutters for glass and ceramic tiles. These methods will work reasonably well with some makes of board, but with other makes you end up with the board smashed into several small pieces.

Bitter experience suggests that the safest approach to cutting stripboard is to use a saw that has a thin blade and fine teeth, such as a hacksaw or junior hacksaw. Cut carefully and slowly along rows of holes. Do not try to cut between the rows as the spacing between them is so small that this is unlikely to give good results. The board must be held firmly in place and the saw should be used with the least amount of pressure that will do the job. Cutting along rows of holes will inevitably give some rough edges, but these are easily filed to a neat finish.

Another problem with stripboard is that it is very easy to produce accidental short-circuits between adjacent strips due to excess solder from one of the joints. This stems from the fact that the gap between the adjacent copper strips is extremely small at about 0.3mm. This can actually be a problem with any form of printed circuit board, but it seems to be more acute with stripboard.

Using a soldering iron with a small bit of about 2mm to 2.5mm in diameter should minimise the problem. As pointed out in these articles many times before, with any printed circuit board it is a good idea to thoroughly check the finished board for accidental short circuits. Scrub the underside of the board with an old toothbrush to clean away any excess flux, and then use some form of magnifier to search for any solder between the tracks.

Got it numbered

A further problem with stripboard is that, unlike a custom printed circuit, it does not have a convenient one hole per pin or lead. In most cases there will be literally hundreds of unused holes, which makes it easy to get components in the wrong positions on the board. It can be time consuming spotting this type of mistake, and in the case of integrated circuits it can be difficult to correct any errors without damaging the board. Some proper desoldering equipment would certainly be required.

Prevention is better than cure, and the positions of components should always be double checked prior to soldering them in place. Stripboard layout diagrams, including all those featured in *EPE*, are normally marked with letters to identify the copper strips and numbers to identify the columns of holes. Adding these markings to the board itself can help to reduce the likelihood of an error being made. With the aid of these markings it is easy to match any point on the board with the corresponding position on the layout diagram.

Marking the board directly can be difficult, but it can be done using a fibre-tip pen having a suitably fine tip and a spirit-based ink. A better way of doing things is to use a computer and printer to produce labelled strips that can be gummed in place on the board (Fig.3). Any drawing program should be able to produce this type of thing accurately to scale, and with a little trial and error it could probably be done using a word processor.

Despite its short-comings, stripboard is an excellent product that can be used to produce quite neat finished boards. It is perhaps not ideal for beginners when building their first few projects, which is probably true of the other construction methods described in this article. It should not be difficult to use once some experience at building boards has been gained, and it is a good choice for those wishing to build simple projects where there is only a circuit diagram to work from and no construction details.

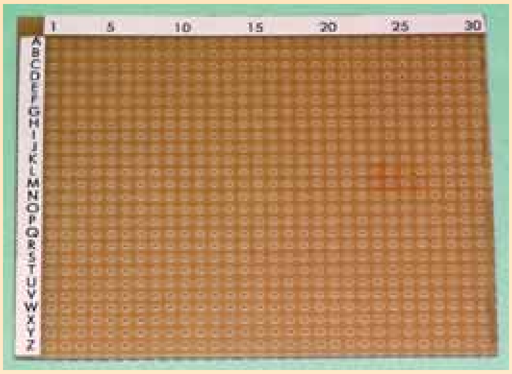

Fig.3. Labelling the rows with letters and the columns with numbers makes it easier to navigate your way around a stripboard. Component layout diagrams often include these markings, but if necessary, you can add them yourself

NET WORK

by Alan Winstanley

Keeping a look-out

IN previous months, I mentioned how webcams had improved in leaps and bounds over the years, with a lowly VGA camera (640 × 480 pixels) being available for as little as £5 ($7) and perfectly good enough for Skype, if you don't mind wearing a separate boom microphone. I recently installed Skype and donated a small webcam to a religious minister who communicates with various missionaries around Africa and India, and his new-found ability to see his subjects via the Internet delighted him.

A higher resolution camera such as the Logitech HD 9000 with Carl Zeiss lens (see *Net Work*, *EPE* Feb'12) costs maybe £40 ($60) or so, and is much better at scanning QR codes or streaming high quality video. Bundled software can recognise facial features and superimpose fun effects on them, and some third-party camera software such as CyberLink's *YouCam 5* can scan your face and log you into a small number of major websites such as eBay.

The software could also be used to create video presentations or podcasts, and it boasts some pretty amazing features, but it can cost as much as a webcam alone. A free demo is available from Cyberlink's website at: **www.cyberlink.com**.

A typical unbranded pan-tilt IP camera. A Wi-Fi antenna is on the rear and a small speaker (not shown) is in the axle pod

Home area networking (HAN) is evolving all the time with a widening and exciting range of peripherals coming on to the market for domestic users, as hardware manufacturers clamour to sell us more gear to hook onto our home-based networks. We can now install media servers to stream music, video, photos or TV over the HAN. Webcams can also be configured as security devices, capturing motion within a defined area and taking snapshots at 640 × 480 pixels.

If you're interested in security or surveillance, then another approach is to hook an IP (internet protocol) camera onto a network. While CCTV cameras connect to a monitor or expensive hard disk recorder, an IP camera is intended to work independently on a local area network. The key attraction is that images can be viewed in a web page, and with careful configuration IP cameras can even be controlled remotely via a web browser or a mobile phone screen.

Lights! IP camera! Action!

IP cameras sound ideal for home surveillance or monitoring purposes, but do they live up to their expectations? I decided to find out by testing a typical device that's widely available. Some cameras are motorised on two axles, which permits the lens to be panned or tilted, and some have a digital zoom. Hence a 'PTZ' camera can pan, tilt and zoom. They are mostly 640 × 480p, and some are fitted with infrared LEDs, offering night vision over a few metres in total darkness, and they may also relay sound through a built-in microphone. As an IP camera acts as a server in its own right, it does not need a host PC and they can connect to a router through an Ethernet cable. However, some IP cameras also have 802.11 Wi-Fi built in, which is something that I wanted to experiment with.

My IP Camera boasted Wi-Fi, pan and tilt, infra-red night vision and two-way sound. It was branded and came with a reasonable little manual that made a good attempt to explain a highly complex product, and it promised UK technical support (help that in the event, never actually came). Many imported unbranded clone cameras reportedly have tissue-thin manuals containing unfathomable instructions that defeated every attempt to make sense of them. Readers won't need to look far on Amazon or eBay to find this camera – a UK electronics chain prices them at just under £100, while identical unbranded ones appear on Amazon at about £40.

My model claims to be accessible in web browsers or mobile phones, so in theory it could be accessed from around the world, and it has various alarm, alert and image uploading features. All this and Wi-Fi too makes for an impressive specification on paper, but how well would they work in practice? This month I outline the basics to look for when installing a typical IP camera like this.

Lens and infra-red LEDs, and LDR (12 o'clock) for low-light level detection. A blinking white LED at 6 o'clock is very distracting, but can be disabled in software

Installation usually requires that the camera is hooked to a router with an Ethernet cable first. Some devices install without a hitch, while others are a day-long nightmare, and sad to say my IP camera eventually fell into the latter category. It's beyond the scope of *Net Work* to get into too much detail as there are hundreds of routers, each with their own configuration to choose from, but to give you a taste of what to expect some key aspects are outlined next.

Plug 'n Playtime

The camera will somehow adopt its own 'internal' IP address on your LAN. How this happens depends on whether you provide an IP manually, or whether you'd like your router to provide it 'on the fly' using DHCP (dynamic host configuration protocol), where an IP number is supplied from a selected

range. So check your router settings to see that DHCP is enabled, if applicable, or you need to configure a static IP manually yourself. Typically, it will be along the lines of 192.168.1.x. Note that this is only an IP address as seen on your network: it is not the address seen by the outside world.

If the camera (and router) offer UPnP – Universal Plug n Play – then the job is made easier: the device will virtually set itself up, and in its favour the new camera popped up on the network map with its own IP without much intervention, thanks to UPnP. You might have to install some software to help with setup, starting with creating a username and password, and UPnP options may be in there too. A MAC address, if seen in the setup screens, is the unique 'media access control' string that identifies that device on the network, and there may be a label on the camera that tallies with it.

My camera was given an 'internal' IP of 192.168.1.112:82 – I chose Port 82 in my installation. There's also the important aspect of 'port forwarding' to consider. With the local area network running behind the router's firewall, then if external nodes (eg, for remote control or viewing purposes) wish to connect to the camera over the web then the packets must be routed through the firewall to the camera's local IP address.

I then set up a port mapping rule manually in my router's virtual server configuration, but readers may see the term port forwarding in their screens instead. The camera's manual should explain what's needed.

When accessing the camera from outside on the web, or on your phone or tablet, then another key consideration is that of DDNS – dynamic domain name system. The question is, how to view your camera if you're halfway round the world. At the very least, you would need to type your public-facing IP address into a web browser, and thanks to your router's port forwarding you could then access the logins of your IP camera on its 'invisible' internal IP address.

The problem is, what happens if your public IP address changes? My broadband connection enjoys a static IP address, which I know will never change, but in the case of dynamic addresses, the IP may change periodically which makes it impossible to know what IP to log into to check the camera. DDNS overcomes this problem. Some IP cameras include a free proprietary DDNS service such as **Viewnetcam.com** (Panasonic): a sub-domain might also be included, so in theory you can forget IP addresses altogether and type *(mycamera)*.**viewnetcam.com** in plain English instead.

The Wi-Fi camera on test included no such service, but if you have a dynamic IP address then consider **No-IP.com** or **dyn.com** (untested by the author). Modest annual subscriptions may be payable for these services and more explanation of the principles of DDNS are given on their web sites.

Patrolling the scene

Round off the initial setting up by inputting your wireless network details, including the network key and encryption type. Next, with the camera still tethered by an Ethernet cable, I connected to it without a problem by typing its local IP address into my PC web browser. The camera's webpage was very reasonable and easy to navigate. I could immediately pan and tilt the lens as well, which could 'patrol' automatically and follow a programmable path (eg, from door to window). The coverage of the motorised camera mount was impressive.

Rear audio jack, Ethernet port, Wi-Fi connector, mysterious 4-way I/O alarm block and power jack. The supplied 5V mains adaptor has quite a short lead

Trying it on Wi-Fi instead, my glee turned to disappointment as many problematic areas emerged. The biggest headache by far was that of Wi-Fi reliability: my device would disconnect from the network at regular intervals even if only 30ft away. Sometimes, it would run all through the night further away, or other times it would not connect at all from just 20ft away with a brick wall in the way.

I could not record any video to hard disk, even though the 'recording' icon was lit, and the camera's built-in SMTP function failed to send an alert email, despite trying several SMTP servers. It was necessary to reboot the camera regularly by unplugging it from the mains (it has an annoyingly short lead on the mains adaptor, which was a major handicap: I've seen DC extension leads sold on Amazon).

Despite these setbacks, it was possible to hear audio, and also to upload images by FTP onto my web server every few seconds when the camera was triggered, though a time lag meant the 'target' might be missed. Night vision also worked well and would be adequate for a smaller room, and the highly distracting blinking white LED near the lens could be disabled in the setup.

Built-in sounds (including a barking dog, or conversation) could be played when triggered, and the camera had a small speaker and audio outlet. The tantalising 4-way terminal block for alarm systems that every *EPE* reader would itch to hook something up to, wasn't described anywhere, and my request for technical details went unanswered.

As for remote access, when it was working on Wi-Fi a colleague managed to log in to my static IP address and swivel the camera around. My experience on a mobile phone wasn't very good; the camera's web page was broken in Windows Mobile IE and Opera Mini, and I only got one snapshot on one occasion – and that was direct over my LAN rather than from outside the network.

So near, yet so far

After struggling for the day, overall I felt that wireless operation wasn't likely to be reliable and that cabled Ethernet would be best, which defeated the object entirely. With several key disappointments evident, I got the feeling of 'so near, yet so far', and it wasn't long before I factory-reset the whole lot and bundled it off back to the supplier, who agreed that they work best on wired Ethernet. You can soon check what other users think by reading their reviews on Amazon.

Panasonic's BL-C131, a popular Ethernet/Wi-Fi pan-tilt camera with sound and PIR, but no IR night vision

An alternative device is Panasonic's BL-C131 or similar, a smart wireless PTZ camera without IR night vision or the same angle of coverage, though it does have 10x zoom and a PIR detector, audio and various user-friendly privacy settings. Its web interface is slightly more primitive than the device tested above, but Panasonic offers a dedicated free DDNS service with a separate web login for mobile phones, which is simple and works well.

Unfortunately, one of these cameras is on my bench after flaking out due to a Wi-Fi module failure (a fault reported on the web), and I have also found this Panasonic model very frustrating to set up at times. However, another Panasonic installation that I'm familiar with has worked flawlessly on 802.11 for several years, so it's pot luck.

It must be accepted that installing this type of device is not as simple as switching on a toaster, but readers should not be deterred from trying these cheaper wireless cameras, mindful of the key points outlined above. There is always the option of using wired ethernet for more consistent results. You might get lucky, but if you enjoy pulling your hair out then installing a Wi-Fi camera might be for you!

I hope you enjoyed this month's *Net Work*. I'm always pleased to hear from readers, but unfortunately I cannot always guarantee an individual reply. Why not drop in at the *EPE Chat Zone* – now with a new Raspberry Pi section – at **www.chatzones.co.uk**. You can email me at: **alan@epemag.demon.co.uk** or write to the editor at **editorial@wimborne.co.uk**

READOUT

Matt Pulzer addresses some of the general points readers have raised. Have you anything interesting to say? Drop us a line!

All letters quoted here have previously been replied to directly

Email: editorial@wimborne.co.uk

☆ LETTER OF THE MONTH ☆

Mains safety issues

Dear editor

The picture in your editorial (*EPE*, July 2012) of the overheated and burnt out mains multi-way adapter, where the neutral pin had melted its mounting and fallen out, was a salutary warning and spoke eloquently for itself. However, there is an excellent calculation that can be done to show why the plug overheated without any apparent warning, apart perhaps from the smell. You have identified the cause of the problem to be a loose connection in the mains socket, but an oxide-tarnished layer on one of the power pins could also have caused it.

It is not unreasonable to assume that the faulty contact or a tarnished pin might have a resistance of 0.1Ω. Typically 10A could be flowing through this contact.

The power (heat) dissipated in the contact is given by:

$$P = I^2R = 10 \times 10 \times 0.1 = 10\text{W}$$

Consider how hot something like a 15W soldering iron gets for about the same mass and surface area of the pin and you can quickly visualise the damage that will be done by this.

Now, why don't we notice a problem like this brewing, until the damage is as bad as shown in your editorial picture?

The voltage drop due to the resistance of the pin contact is given by:

$$V = IR = 10 \times 0.1 = 1\text{V}$$

This volt drop would simply not be noticed in the operation of any equipment, and the first you may know about it would be the smell if you are lucky, or worse, smoke or flames.

It is not surprising to me that it was a cube multi-way adapter that had suffered the problem because by their dimensions they can exert an excessive leverage on the pins in the wall socket, which leads to slackening of the gripping force of the contacts. Fire officers will always preach against such devices – and they should know!

In your case, the current flowing was only a few amps, so what probably happened was that the poor internal contact generated a small amount of heat. This was enough to encourage the tarnishing of the conductor surfaces and so the contact resistance increased further. This in turn would have lead to more heat and faster tarnishing, with yet more resistance increase, until the results shown occurred. I would estimate, considering the damage shown and using the above calculations, that the resistance might have reached 0.5Ω or more.

The situation that made me sit up and take notice of this effect was in a large chemistry research lab. As the maintenance technician, I found I was replacing a plug, on average, every day, due to them getting hot! The caustic atmosphere in the labs vastly accelerated the oxidised tarnish of the pins. Goodness knows what it was doing to our lungs, but this was before the days of safety officers with power. Unlike some, I don't hanker back to those 'good old days'! Interestingly, the sockets themselves did not seem to tarnish to the same extent as the plugs, and I only had to change a few sockets in contrast. The test was to see if a new plug heated up when used on high current in the socket.

The worst case I've actually seen was a consumer unit where the line bus bar had actually melted away, with all the attendant damage this caused. Thankfully, no fire was caused because the consumer unit acted as its own fuse and interrupted the supply!

The fault appeared to have been caused by the installation 'sparky' neglecting to tighten up the contact screws fully. The new untarnished state of the bus bar and screws allowed the consumer unit to operate correctly with adequate conductivity to pass all the commissioning tests, but a few years down the line, tarnish started to appear under the screws, resulting in the same run away situation as happened with your editorial multi-way

Dave Bush, Leamington Spa

Matt Pulzer replies:

Your letter makes a lot of sense and is a further important warning that an 'it'll do' attitude to mains wiring and accessories is never ever acceptable. We should all remember the power behind our trusty 13A wall sockets and not take them for granted.

Raspberry Pi ideas

Dear editor

At £30, the Raspberry Pi can either be used as a replacement PIC processor or could provide back-end data processing and a powerful display for hardware. The main issue is that the Raspberry Pi operating system (OS) is based on LINUX, so there is a big learning curve for many new users. Given this, I'd like to suggest the following ideas: • Web server • An introduction to using the Guertboard or development of one or more I/O boards for various purposes • There is, I believe, a camera connector on the board – how to interface and use this device • Robototics – using the Raspberry Pi wirelessly, with a camera, other I/O possibilities • Interface to an Arduino or chipKIT board • Integrated test equipment suite, making use of the USB and Ethernet connections • Beginner's oscilloscope • Weather station • Audio analyser • Universal home controller – to replace those small handsets we all acquire (include an LCD display) • Light organ – a bit of OTT fun

Ashoke Patel, by email

Matt Pulzer replies:

Hi Ashoke

Thanks for your email and very interesting comments and project ideas.

I am not sure what software approach we will take with Raspberry Pi – that is really down to Mike Hibbett who writes our Pic 'n Mix *column. However, I have passed on your comments and project ideas to him and I hope we will hear from him soon.*

I think your suggestion of a 'beginner's oscilloscope' is particularly interesting

Mike Hibbett replies:

Hi Ashoke
Thanks for the suggestions – these are all appreciated. I particularly like your suggestion about an introduction to the Guertboard. We will probably produce a design for own board, as it will be simple enough and will help encourage people to make their own.

I agree about Linux being a steep learning curve – it's even difficult for professionals! We will be providing tutorials on building your own Linux distributions for the Pi, but any projects we create will have the 'build your own' and 'here is one we made earlier' options for those people who are not interested or ready yet to start delving into the 'black art' of Linux systems.

It's not all that bad though; there are many software tool kits that simplify building embedded Linux software. We will probably pick one and stick to it.

In the 'Zone'

Dear editor
Greetings from South Africa – and grateful thanks, not only for a fine magazine, but also to whoever came up with idea of the *Chat Zone*!

I have been a member of the 'Zone' for some time, and can honestly say that without it, I would have battled extensively trying to find solutions to some of the problems I have been faced with.

I am located on a farm in a very remote area of the country. The nearest supermarket, for instance, is over 40km away!

My grandiose ideas to develop and apply some measure of automation to the farm would never have had successful outcomes if it wasn't for the 'Zone' members who give so freely of their time and considerable expertise.

I realised early on that it didn't matter how trivial or complex the query – there was always an answer. And, more often than not, the answer was simple, innovative, remarkably clever and it worked!

To gather a group of consultants such as those to be found on the Zone would be exorbitant financially. But here, thanks to *EPE*, a resident band of gurus are always there to help their fellow enthusiasts with their hare-brained ideas.

I often chuckle to myself when formulating a query to the Zone, with a strong mental image, as I click the submit button, of an intense group of individuals separated by vast distances, all hunched over their keyboards, waiting, waiting, waiting in eager anticipation of a query or comment delivered at light speed to their screens. Their minds engage high gear and the game is on! Comments and solutions fly thick and fast, always technically competent, often innovative and usually with high good humour.

I salute you all and offer my humble and grateful thanks for your time, expertise and 'out of the box' thinking that has helped to make my endeavours on the farm successful.

More than that – to the faceless someone who conceived the idea of the *Chat Zone* – I just don't have the words to tell you adequately how much I appreciate your foresight in providing this experience to all us 'solder dabblers'.

Brian Connell, South Africa

Matt Pulzer replies:

It's great to hear of your successful use of the 'Zone' – I rather like your abbreviation by the way. Your thanks should go to Alan Winstanley our on-line editor.

Lab-standard 16-bit Digital Pot

Dear editor
Having built a *Precision 10V Source* (*EPE*, June 2011) I was interested in the *16-bit Digital Pot* article (July '12). I've used the 10V source to check readings on the 20V range of the modestly priced DMMs I have. The digital pot would enable me to check the full-scale reading of the 2V and 200mV ranges, as well as a few intermediate points – but certainly not all 65,536!

The 10V source I've built uses the 10V ±3mV chip; any source will have some inherent error, which will be a fundamental additional error to be accounted for in the overall accuracy of the output of the digital pot. The tolerance of the resistors of the divider chain looks to be the major source of error at first glance.

Jim Rowe's Fig.3 (measured with some very precise instrument presumably) suggests that in his design it is within a ±1mV band. This is a very acceptable figure. Jim states that the load impedance should not be below 1.5MΩ. However, my DMMs have a 1MΩ input impedance, so I had a look at what effect it would have.

At mid-range point, with perfectly matched resistors and a 10V source, the output should be 5.000V. This is formed from a divider of a single 3kΩ top-end resistor and 3kΩ at the bottom (made from the series/parallel connection of the other resistors).

Adding an output load of 1MΩ lowers the bottom end slightly and drops the output to 4.9925V; ie, an error of –7.5mV. At this setting the output is very sensitive to the top-end resistor, and if it is on the high side by 0.1% then this error increases to about –10mV. The tolerance of the bottom end will not be so significant in this case as it is made from 31 resistors; so, statistically, the errors will be reduced.

This 'loading' error affects other output values and increases at the higher values of output. It can be calculated from the load and the output impedance of the divider, which is 1.5kΩ at all settings. Thus, for a load of R, the output is reduced to $Vo \times R/(R + 1.5k\Omega)$ at an output voltage of Vo. At 10V output, with a 1MΩ load, the output is low by 15mV, which is about 100 LSBs. This suggests that a unity-gain buffer with a very high input impedance is desirable to reduce this loading error; the buffer must also have a very low input offset voltage, ideally less than half the step size; ie, <76μV. If the loading effect of the buffer is to cause no more than 1 LSB drop in voltage, then its input impedance needs to be more than 96MΩ. It may be possible to work with a lower value of impedance and higher offset, as with known values the software of the controller could compensate for them.

Ken Naylor, by email

Matt Pulzer replies:

Excellent analysis Ken, and bears out my belief that in electronics you can often produce truly professional results with careful thought and straightforward mathematics.

Chip programming

Dear editor
We just ordered and received the PCB for the *Power Tool Charger Controller*. We were hoping to have Magenta program the PIC16F88P for us. However, we have received an email from them saying that they do not program PICs any longer. Can you recommend someone else who could program the PIC for us?

Hope to hear from you soon!

Michael Kelley, by email

Alan Winstanley replies:

Hi Michael
Magenta Electronics discontinued their service some time ago (about two years) in order to concentrate on manufacturing their own products.

I don't know of any other company offering to program individual chips, and if Magenta found it non-viable then I guess there is a message there. However, as this question keeps on cropping up I am looking at some other options.

In the meantime, readers have helped each other out by asking in EPE*'s* Chat Zone*. I have found they usually trade or swap and sort something out that way. We have also, in the recent past, published a simple 'Get Started' article to help those wanting to burn their own chips for the first time.*

I appreciate your interest, but unfortunately, asking in the Chat Zone *forum is all I can suggest at present.*

Matt Pulzer replies:

Hi Michael
I appreciate that programming PICs is not for everyone, but if you are concerned that it's too difficult then please reconsider, or at least read the article Programming PICs: How It's Done*, which appeared in our February 2012 issue. It really isn't hard and will give you just a little more of that 'I made this' feeling of achievement!*

Sawtooth fan!

Dear editor
I was particularly impressed by Robert Penfold's sawtooth waveform generator featured in this month's (August 2012) Interface *as shown in Fig.3 on page 65.*

I had difficulty working out how this clever little circuit actually operated, but after breadboarding it, all was revealed!

The positive and negative-going ramps actually rise and fall in a linear manner, unlike the normally seen exponential fashion of a typical relaxation oscillator, as in this month's (Aug '12) DC Motor Speed Controller*.*

In Robert's oscillator, pin 2 and pin 3 of IC3a are held at the same constant voltage, while pin 1 rises and falls repeatedly, triggering the non-inverting Schmitt trigger based around IC3b. Pin 1 is forced to change its voltage level in order to maintain the inputs at the same voltage as 'positive' charge is added to or removed from the lower side of capacitor C2 via resistor R7. When the output of IC3b is high, pin 1 is ramping downwards and when the output is low, pin1 is ramping upwards. C2, the 100nF timing capacitor, is always being charged or discharged by a constant current caused by the constant voltage across R7.

Maybe I'm impressed easily, but not having seen this circuit before I found its operation very novel and interesting. Great stuff Robert!

James, via *EPE Chat Zone*

Alan Winstanley replies:

Many thanks for this feedback James, which I'm passing on to Robert. It's always rewarding to get appreciative comments like these from readers.

Alan Winstanley, *EPE* on-line editor
Readers can contact Alan by email at: alan@epemag.demon.co.uk

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ROBOTICS

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Robert Penfold

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Detailed building instructions are provided for the featured robots, including numerous step-by-step photographs. The designs include rover vehicles, a virtual pet, a robot arm, an 'intelligent' sweet dispenser and a colour conscious robot that will try to grab objects of a specific colour.

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This *Teach-In* series of articles was originally published in *EPE* in 2008 and, following demand from readers, has now been collected together in the *Electronics Teach-In 2* CD-ROM.

The series is aimed at those using PIC microcontrollers for the first time. Each part of the series includes breadboard layouts to aid understanding and a simple programmer project is provided.

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The CD-ROM also contains all of the software for the *Teach-In 2* series and *PIC N' Mix* articles, plus a range of items from Microchip – the manufacturers of the PIC microcontrollers. The material has been compiled by Wimborne Publishing Ltd. with the assistance of Microchip Technology Inc.

The Microchip items are: MPLAB Integrated Development Environment V8.20; Microchip Advance Parts Selector V2.32; Treelink; Motor Control Solutions; 16-bit Embedded Solutions; 16-bit Tool Solutions; Human Interface Solutions; 8-bit PIC Microcontrollers; PIC24 Micrcontrollers; PIC32 Microcontroller Family with USB On-The-Go; dsPIC Digital Signal Controllers.

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ELECTRONICS TEACH-IN 3

The three sections of this book cover a very wide range of subjects that will interest everyone involved in electronics, from hobbyists and students to professionals. The first 80-odd pages of Teach-In 3 are dedicated to *Circuit Surgery*, the regular *EPE* clinic dealing with readers' queries on various circuit design and application problems – everything from voltage regulation to using SPICE circuit simulation software.

The second section – *Practically Speaking* – covers the practical aspects of electronics construction. Again, a whole range of subjects, from soldering to avoiding problems with static electricity and indentifying components, are covered. Finally, our collection of *Ingenuity Unlimited* circuits provides over 40 circuit designs submitted by the readers of *EPE*.

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COMPUTERS AND COMPUTING

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PROGRAMMING 16-BIT PIC MICROCONTROLLERS IN C – LEARNING TO FLY THE PIC24 Lucio Di Jasio (Application Segments Manager, Microchip, USA)

A Microchip insider tells all. Focuses on examples and exercises that show how to solve common, real-world design problems quickly. Includes handy checklists to help readers perform the most common programming and debugging tasks. FREE CD-ROM includes source code in C, the Microchip C30 compliler, and MPLAB SIM software, so that readers gain practical, hands-on programming experience.

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Ian Waugh

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Whether you want to stay bang up to date with the latest music or create your own MP3s and join the on-line digital music revolution, this book will show you how.

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DIGITAL AUDIO RECORDING
Ian Waugh

All modern music recordings use digital audio technology. Now everyone with a computer can produce CD-quality recordings and this book shows you how.
Written in a clear and straightforward style, it explains what digital audio recording is, how to use it, the equipment you need, what sort of software is available, and how to achieve professional results.

It explains:
- What computer system you need
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- What to look for in a sound card
- What effects to use
- The art of mixing
- Recording techniques
- How to use virtual instruments
- How to edit audio and create loops

Computer-based recording is the future of music and this book shows how you can join the revolution now.

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RADIO BYGONES

We also carry a selection of books aimed at readers of *EPE*'s sister magazine on vintage radio *Radio Bygones*. These books include, the four volumes of our own *Wireless For the Warrior* by Louis Meulstee. These are a technical history of radio communication equipment in the British Army and clandestine equipment from pre-war through to the 1960s.
For details see the UK shop on our web site at www.epemag.com or contact us for a list of *Radio Bygones* books.

PROJECT BUILDING AND TESTING

ELECTRONIC PROJECT BUILDING FOR BEGINNERS
R. A. Penfold

This book is for complete beginners to electronic project building. It provides a complete introduction to the practical side of this fascinating hobby, including the following topics:

Component identification, and buying the right parts; resistor colour codes, capacitor value markings, etc; advice on buying the right tools for the job; soldering; making easy work of the hard wiring; construction methods, including stripboard, custom printed circuit boards, plain matrix boards, surface mount boards and wire-wrapping; finishing off, and adding panel labels; getting "problem" projects to work, including simple methods of fault-finding.

In fact everything you need to know in order to get started in this absorbing and creative hobby.

135 pages **Order code BP392** **£5.99**

BUILDING VALVE AMPLIFIERS
Morgan Jones

The practical guide to building, modifying, fault-finding and repairing valve amplifiers. A hands-on approach to valve electronics – classic and modern – with a minimum of theory. Planning, fault-finding, and testing are each illustrated by step-by-step examples.

A unique hands-on guide for anyone working with valve (tube in USA) audio equipment – as an electronics experimenter, audiophile or audio engineer.

Particular attention has been paid to answering questions commonly asked by newcomers to the world of the vacuum tube, whether audio enthusiasts tackling their first build, or more experienced amplifier designers seeking to learn the ropes of working with valves. The practical side of this book is reinforced by numerous clear illustrations throughout.

368 pages **Order code NE40** **£29.00**

PRACTICAL FIBRE-OPTIC PROJECTS
R. A. Penfold

While fibre-optic cables may have potential advantages over ordinary electric cables, for the electronics enthusiast it is probably their novelty value that makes them worthy of exploration. Fibre-optic cables provide an innovative interesting alternative to electric cables, but in most cases they also represent a practical approach to the problem. This book provides a number of tried and tested circuits for projects that utilize fibre-optic cables.

The projects include:- Simple audio links, F.M. audio link, P.W.M. audio links, Simple d.c. links, P.W.M. d.c. link, P.W.M. motor speed control, RS232C data links, MIDI link, Loop alarms, R.P.M. meter.

All the components used in these designs are readily available, none of them require the constructor to take out a second mortgage.

132 pages **Order code BP374** **£5.45**

GETTING THE MOST FROM YOUR MULTIMETER
R. A. Penfold

This book is primarily aimed at beginners and those of limited experience of electronics. Chapter 1 covers the basics of analogue and digital multimeters, discussing the relative merits and the limitations of the two types. In Chapter 2 various methods of component checking are described, including tests for transistors, thyristors, resistors, capacitors and diodes. Circuit testing is covered in Chapter 3, with subjects such as voltage, current and continuity checks being discussed.

In the main little or no previous knowledge or experience is assumed. Using these simple component and circuit testing techniques the reader should be able to confidently tackle servicing of most electronic projects.

102 pages **Order code BP239** **£5.49**

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Printed circuit boards for most recent *EPE* constructional projects are available from the *PCB Service*, see list. These are fabricated in glass fibre, and are fully drilled and roller tinned. Double-sided boards are **NOT plated through hole** and will require 'vias' and some components soldering to both sides. All prices include VAT and postage and packing. Add £2 per board for airmail outside of Europe. Remittances should be sent to **The PCB Service, Everyday Practical Electronics, Wimborne Publishing Ltd., 113 Lynwood Drive, Merley, Wimborne, Dorset BH21 1UU. Tel: 01202 880299; Fax 01202 843233; Email: orders@epemag.wimborne.co.uk. On-line Shop: www.epemag.com**. Cheques should be crossed and made payable to *Everyday Practical Electronics* **(Payment in £ sterling only)**.

NOTE: While 95% of our boards are held in stock and are dispatched within seven days of receipt of order, please allow a maximum of 28 days for delivery – overseas readers allow extra if ordered by surface mail. Back numbers or photocopies of articles are available if required – see the Back Issues page for details. WE DO NOT SUPPLY KITS OR COMPONENTS FOR OUR PROJECTS.

Please check price and availability in the latest issue. A large number of older boards are listed on, and can be ordered from, our website.

Boards can only be supplied on a payment with order basis.

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– Radio Loop	814	
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★SD Card Music & Speech Recorder/Player	815	£13.61
★Deluxe 3-Chan. UHF Rolling Code Remote Control – Transmitter	816 } pair	£12.43
– Receiver	817	
SEPTEMBER '11		
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Auto-Dim for 6-Digit GPS Clock	819	£6.80
OCTOBER '11		
★ High-Quality Stereo DAC –		
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PROJECT TITLE	ORDER CODE	COST
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Dual Tracking ±0V to 19V PSU		
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– LCD Meter	853	£7.19
Jump Start Quiz Machine		
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★ All software programs for *EPE* Projects marked with a star, and others previously published can be downloaded free from the Library on our website, accessible via our home page at: **www.epemag.com**

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PCB masters for boards published from the March '06 issue onwards can also be downloaded from our website (**www.epemag.com**); **go to the 'Library' section.**

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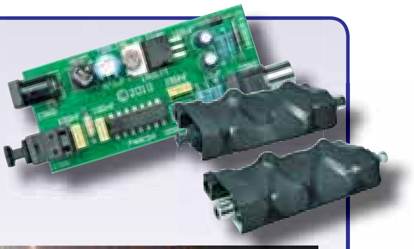
Next Month

Content may be subject to change



Two TOSLINK–S/PDIF Audio Converters

Do you have a DVD or CD player with a TOSLINK (optical) output, but only coaxial S/PDIF inputs on your amplifier? Or do you have the opposite problem?
What about hum from your speakers when running digital audio via a coaxial cable?
With these simple converters you can easily solve these problems.

Digital Lighting Controller

Want one up on your neighbours? Instead of a static Christmas Lights display (so passé!) now you can have the ultimate in Christmas extravaganzas. This amazing controller will bring your Christmas lights to life. It's easy-to-build, easy-to-connect and, best of all, easy to program!

Jump Start

Before you build the Christmas light controller, how about this Halloween 'spooky' sound generator? In next month's *EPE*, Mike and Richard Tooley build a 'Wailing Siren with flashing lights' the sixth project in our new series dedicated to newcomers, or those following courses taught in schools and colleges.

Ultrasonic anti-fouling for boats – Part 2

In Part 1, we published the details of the ultrasonic driver for this project, which is housed in an IP65 case for safety and protection from water ingress. This month, we describe how to encapsulate the ultrasonic transducer so that it is safe to handle.

Designing and installing a hearing loop for the deaf – Part 2

In Part 1, we introduced the subject of hearing aid inductive loops and explained how they were designed. We also mentioned that most amplifiers could be used to drive hearing loops, albeit with a bit of tweaking in most cases. Now we move on to some of the commercial equipment designed specifically for driving hearing loops.

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